Air Repair

Kiln Stack discharging 14,000 cfm from electrostatic precipitator
(See Page 185)

AIR POLLUTION CONTROL ASSOCIATION

4400 FIFTH AVENUE PITTSBURGH 13, PA.

FOUNDED 1907

Air Repair

A QUARTERLY JOURNAL DEVOTED TO AIR PURIFICATION

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of these opinions.

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The Reduction of Atmospheric Pollution from Sulfuric Acid Recovery Processes

By N. W. Clauss
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South Charleston, West Virginia

It is evident that production of industry will eventually be restricted unless processes which contribute to pollution, are operated in a manner which will not be objectionable to the public.

The concentration of sulfuric acid can be done economically in vacuum type concentrators with no atmospheric pollution problem if the desired acid strength does not exceed about eighty per cent. Above this strength it is generally more economical to use air-blown concentrators because of the lower cost of the heat required.

The chemical industry has an extensive investment in air-blown acid concentrators and the problem of atmospheric pollution resulting from such installations is a major one.

Data obtained from the operation of a recovery process concentrating sulfuric acid in both vacuum and air-blown concentrators has shown that the control and elimination of obnoxious gaseous effluents is quite complex. The effluent gases from air-blown concentrators contain sulfuric acid mist, and sulfur dioxide resulting from the decomposition of sulfuric acid by carbonaceous materials present in spent acid. The ground level concentration of sulfur dioxide can, in most cases, be decreased sufficiently by the use of adequately designed stacks, but the properties of sulfuric acid mist are such that the opaque white appearance of the effluent can be seen for miles.

A pilot plant unit was installed and operated for the purpose of studying the removal of acid mist from the effluent wastes of the acid concentrators. The results of the data obtained eliminated from consideration methods that proved unsatisfactory, and showed the method most suitable for the process concerned. A plant scale unit has been designed and installed, based on this data, to remove acid mist from the concentrator effluent gases. The results of both the pilot plant and plant scale operation will be discussed.

Pilot Unit—General

The pilot unit was designed to handle 600 standard cubic feet per minute of acid fume gases. The removal of sulfuric acid mist by low pressure water sprays, high pressure water sprays, bag filters and by decomposition with heat was to be studied. Although it was known that the use of low pressure water sprays was inefficient for the removal of acid mist, this system was necessary for the operation of the pilot unit, and data were obtained on its efficiency and water requirements.

The air-blown concentrators were originally equipped with Cottrell precipitators for the removal of sulfuric acid mist. The use of electrostatic precipitation was not included in the pilot unit work since the mist removal efficiency was found by previous investigation to decrease greatly as the concentration of acid mist in the inlet gases decreased, and the concentration of acid mist in the precipitator effluent gases was not less than 20 mg. per cubic foot although the concentrators were operating satisfactorily.

The use of high frequency sound wave equipment and various types of water scrubbers for the removal of acid mist were also considered for study, but were rejected on the basis of higher maintenance cost, and because of predicted higher operating costs as compared to the methods studied for the acid recovery process concerned.

Low Pressure Water Spray System

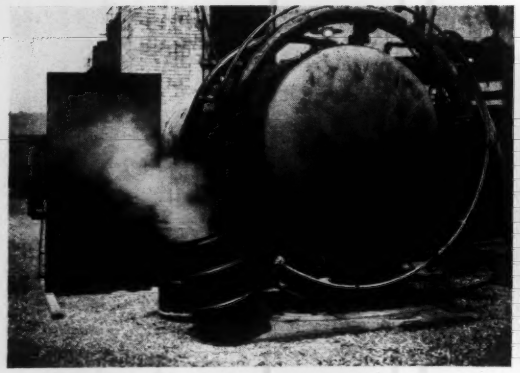
All available data indicated that efficient removal of sulfuric acid mist from concentrator effluent gases was not possible with water spray systems operating at normal pressures. The results obtained, however, show that about 85 to 90 per cent of the acid mist and 25 per cent of the sulfur dioxide were removed from the gas stream when 150 gpm of water, at a spray nozzle pressure of 20 psi, was used. At higher spray nozzle pressures the water requirement decreased. The data were obtained by using from two to eight, normal pressure, spray nozzles in the 12-inch diameter spray tower. The operation of the low pressure spray tower did not remove all of the visible acid mist in any case.

Bag Filter

The bag filter used had 25.3 square feet of filter area and the resulting pressure drop, for the fabrics used, was 0.5 inch of water at a gas flow rate of 500 standard cubic feet per minute. Under these conditions the gas flow was 19.7 cubic feet per square foot of filter fabric. Practically no acid mist was removed from the gas stream with the filter fabrics available at the time of the pilot unit operation.

Acid Fume Furnace

Effluent gases containing sulfuric acid mist in concentrations of 10 to 500 mg. per standard cubic foot were heated with fuel gas to temperatures as high as 1100° C. in the acid fume furnace. The effluent gas contained 16.7 per cent oxygen on a dry basis and was used for the combustion of the fuel gas.



Slide No. 1

Slide No. 2

Slide No. 3

Slide No. 4

Analyses were made to determine the conversion of sulfuric acid mist to sulfur dioxide. The data show an increase in the per cent conversion to sulfur dioxide, with increasing furnace temperature. However, the stack gas from the furnace was invisible regardless of the inlet mist concentration or the operating temperature. The gas velocity through the furnace was about 6.5 feet per second.

Forty per cent of the hot exit gas from the furnace was passed over a 155 square foot helical coil, through which water was circulated to cool the effluent. The gas left the cooler at 115°C. and had the characteristic blue haze as seen in most sulfur dioxide containing gases. The remaining 60 per cent of the furnace exit gas was discharged directly to the atmosphere at 700° C. and was invisible at all times.

However, the use of this type of system for fume removal would be complicated and more expensive to install than the high pressure water spray system which was used.

High Pressure Water Fog System

References have been made in the literature to the use of fog spray nozzles, at high pressures, for the removal of dusts and mists. A 30-inch and a 12-inch diameter spray chamber were installed to study the mist removal efficiency of such systems. Data on water requirements, spray water pressures, gas velocities and other variables were obtained.

The type of fog spray nozzle used for the pilot unit work was determined by a study of the spray characteristics of many nozzles supplied by manufacturers. Each nozzle was calibrated at pressures from 200 to 1000 pounds and photomicrographs were taken to determine the particle size of the droplets produced, when discharging at 500 pounds per square inch.

A photomicrograph of the spray droplets from the nozzle used, is shown in the next slide, 1A.

The nozzle used had an orifice diameter of 0.0495 inches, and the water velocity at the orifice was calculated to be about 180 feet per second, at a nozzle pressure of 500 pounds. The average linear diameter of the water droplets was found to be 9.5 microns.

The 30-inch diameter spray chamber was equipped with nine fog nozzles mounted in three horizontal planes, with three nozzles at each plane. The acid fume gases entered tangentially at the bottom of the chamber at the rate of 600 standard cubic feet per minute containing varying amounts of acid mist.

Spray nozzle pressures were varied from 200 to 1000 pounds with combinations of three, six or nine nozzles in service. It was apparent from the first that the removal of sulfuric acid mist from the gas stream was satisfactory since the effluent gases from the pilot unit were invisible.

The spray nozzle bodies used were at a 45-degree angle to the nozzle connection and the position of the nozzles was changed to project the water either countercurrent or concurrent to the direction of flow of the gas stream. The removal efficiency was not affected by the direction of flow, but appeared to be somewhat affected by the concentration of mist in the inlet gas stream. At a spray nozzle pressure of 1000 pounds, all visible acid mist was removed with six spray nozzles in operation at a water flow of 8 gallons per minute.

Nozzle Pressure Varied

With nine spray nozzles in operation, the spray nozzle pressure was varied from 200 to 1000 pounds and the data indicated that the per cent removal of acid mist increased from 60 to 95 per cent. At 500 pounds nozzle pressure, 82 per cent of the mist was removed with a water usage of 9.0 gallons per minute. The superficial gas velocity through the 30-inch spray chamber was 2.8 feet per second.

Test runs were made at low mist removal efficiency levels to determine the effect of wetting agents. The wetting agents were dissolved in the feed water to the spray nozzles, and no beneficial effect was noted.

Experimental runs were next made in the 12-inch diameter spray tower in which the gas velocity was 19.3 feet per second. Eight fog nozzles were used and the direction of the water spray was concurrent with the gas flow.

The data obtained in the 12-inch spray tower were much more precise and consistant than that obtained in the 30-inch spray chamber, probably due to a decrease in gas flow turbulence.

The mist removal efficiency was considerably higher in the 12-inch spray tower than in the 30-inch tangential spray chamber. For example, the efficiency was 95 per cent at a spray pressure of 500 pounds and a water rate of 6 gallons per minute as compared to the result just stated for the 30-inch diameter chamber. The increased efficiency is probably due to an increase in the number of collisions of water and acid mist particles.

The removal efficiency at a water rate of 6 gallons per minute was essentially constant at pressures above 500 pounds and it was concluded that for a plant scale installation, 500 pounds water pressure would be adequate.

Mist Removal

The analytical data indicated that the method of analysis for acid mist concentrations was accurate to 2 mg. per standard cubic foot. It was felt that at high mist removal efficiencies, the analytical method was not capable of giving results which could be satisfactorily correlated.

Most data on mist removal equipment, reporting high removal efficiencies, are usually obtained with relatively high concentrations of acid mist in the gas inlet stream. Removal efficiencies decrease greatly with low mist concentrations and consequently, rather than relying on efficiency data, the actual concentration in the effluent gas should be determined. A mist concentration of less than 10 mg. per cubic foot is necessary for good appearance.

A series of visual tests were made by photographing the effluent gases from the pilot unit. Pictures were taken at varying water rates and pressures and are shown in the following slides:

Slide 1 shows the effluent when no sprays were in service.

Slide 2 shows the result with 2 sprays in service at 500 pounds.

Slide 3 shows the improvement with four sprays in service at 500 pounds.

Slide 4 is with six sprays in service.

Slide 5 shows a clear effluent with seven nozzles in operation at 500 pounds.

A similar series of photographs were made at spray pressures of 1000 pounds.

Slide 1 also shows the appearance of the effluent with all nozzles turned off.

Slide 6 shows the effluent with one nozzle in operation at 1000 pounds.

Slide 7 shows the effect with three nozzles in service.

Slide 8 shows the effluent with five nozzles in service and shows a clear effluent.

Slide 9 shows the effluent with six nozzles in service.

The water rate required to produce an invisible effluent at 500 pounds per square inch was 6 gallons per minute with seven nozzles in operation. The same result was obtained at 1000 pounds with 5 nozzles in operation, although the spray water rate remained the same. The photographs were made for this test run at essentially constant atmospheric humidity conditions.

The humidity on stack appearance was also measured by a series of photographs when 92.5 per cent of the acid mist was being removed from the effluent gases. The following slides show the effect of humidity on the dispersion of the water saturated effluent gases:

Slide 9 shows the effluent at a relative humidity of 90 per cent.

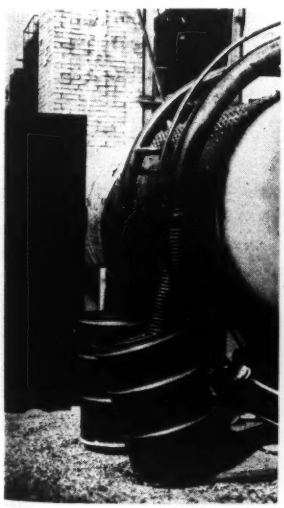
Slide 10 shows the effluent at a humidity of 70 per cent.

Slide 11 shows a considerable improvement in appearance when the relative humidity dropped to 60 per cent.

Inlet acid mist concentrations had very little effect on removal efficiency in the 12-inch diameter spray tower in the range studied.

The removal of sulfur dioxide from the acid fume gases was approximately 5 per cent in both the 30 and 12-inch diameter spray units. The removal of sulfur dioxide in the plant scale unit does not exceed 2 per cent. The low

Slide No. 5



Slide No. 6

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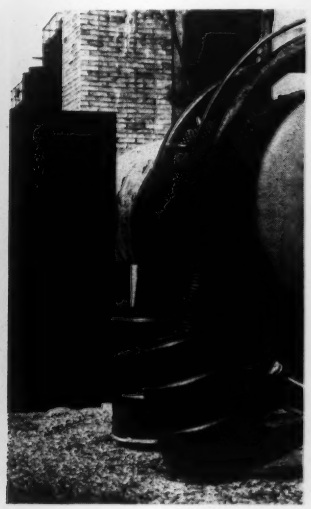

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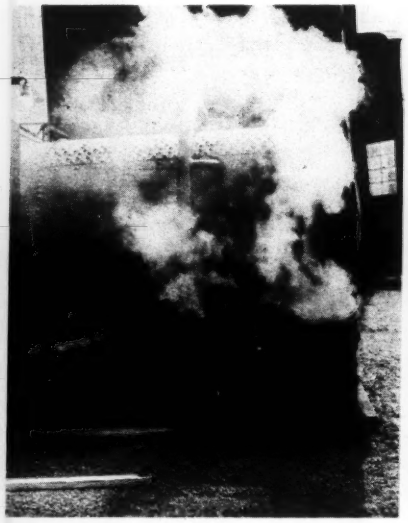

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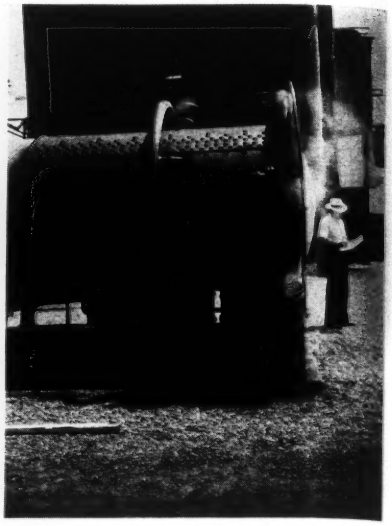


Slide No. 11

removal of sulfur dioxide is due to the low absorption rate at the temperature of 60° C. existing in the spray chamber.

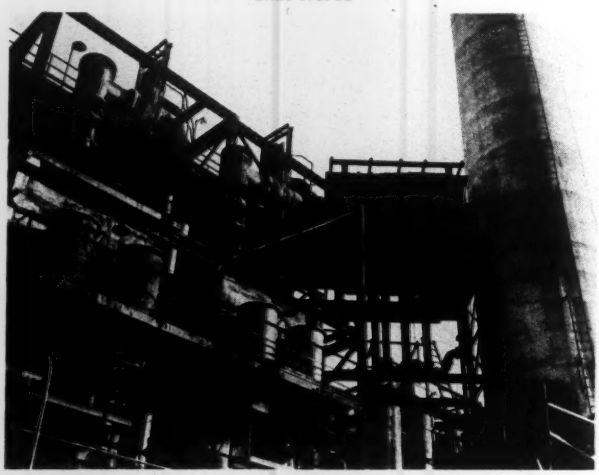
Plant Scale Unit—Description

The data obtained from the pilot unit operation were used for the design of a plant scale unit, since the high pressure water spray method of mist removal was successful and readily adaptable for use at the sulfuric acid recovery plant.

The manufacturing process concerned uses approximately 700 tons per day of sulfuric acid, the spent acid being concentrated from 70 to 95 per cent in five air-blown concentrators. The effluent gases discharge into a common duct through which the gases are transferred to a plenum chamber and then to a fume stack which exhausts the total effluent at 200 feet above ground level.

The volume of the effluent gases from the concentrators is about 89,000 cubic feet per minute at an average temperature of 166° C. The gases contain from 60 to 120 mg. per standard cubic foot of sulfuric acid mist.

Slide No. 12



The plenum chamber, with a cross sectional area of 98.9 square feet, was used as the spray unit and is shown in Slide 12. Five spray banks, containing 99 nozzles per bank, were installed to supply the spray water.

Slide 16 shows one spray bank in operation. The unit was designed to spray 500 gallons of water per minute at 540 pounds spray nozzle pressure. The water is transferred from the spray chamber to the pump suction by gravity flow.

The spray nozzles are equipped with fine mesh screens, and suitable filters were installed in the water transfer lines, to prevent clogging of the nozzles.

Two four-stage centrifugal pumps driven by 180 horsepower steam turbines were to be installed to recycle the spray water. The equilibrium concentration of sulfuric acid in the recycle system was to be about 3.0 per cent when pumping 50 gallons per minute to the manufacturing process and replacing with an equivalent amount of process water.

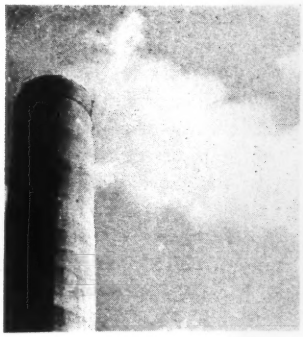
Corrosion and Erosion

Based on corrosion data obtained during the pilot unit operation, the spray nozzles and recycle water pumps were constructed of what was thought to be the best material of construction. However, the effect of erosion could not be satisfactorily evaluated, and severe erosion of the pump impeller and spray nozzles occurred with the recycle system used.

The unit was quickly converted to a single pass water system using process water available from the manufacturing unit. With this system, the water is returned to the manufacturing process containing sulfuric acid in the amount of 4 to 7.5 tons per day.

Four inspirator type fuel gas burners, with a total capacity of 8000 cubic feet per hour of fuel gas, were in-

Slide No. 13



Slide No. 14

Slide No. 15

Slide No. 16

stalled in the base of the acid fume stack to raise the temperature of the saturated effluent gases from 60°C. to 100°C. At this temperature the relative humidity of the gases is 5 per cent and no precipitation of water occurs in the stack.

Performance of Plant Scale Unit

The plant scale acid mist removal unit was put in service with only one pump available because of delays in fabrication. The average acid mist concentration in the concentrator effluent gases was decreased from 117 to 37 mg. per standard cubic foot with only three of the five spray banks in service. The water spray rate was 240 gallons per minute at 540 pounds per square inch. The acid mist removal efficiency was 68.5 per cent, and 5.9 tons per day of sulfuric acid were recovered. The water usage was 2.7 gallons per minute per 1000 cubic feet of gas at flow conditions.

The removal efficiency was increased to over 95 per cent when the effluent gases from only three of the five concentrators were discharging into the acid fume duct. This load duplicates design conditions. The water usage was 4.5 gallons per minute per 1000 cubic feet of gas at flow conditions. The next slide, 16a, shows the stack effluent to be invisible.

The acid mist removal efficiency of the plant scale unit appears to be higher than the efficiency obtained in the pilot unit spray tower. The increase in efficiency is probably due to the elimination of wall effects which existed in the 12-inch diameter spray tower.

The photographs of the acid fume stack effluent shown in the following slides show the effect of spray nozzle pressure on the acid mist removal efficiency with four acid concentrators in operation but only three of the five spray banks in service.

Slide 13 shows the effluent leaving the stack with the spray unit out of service.

Slide 14 shows the reduction in visible acid mist when the spray nozzle pressure was at 300 pounds.

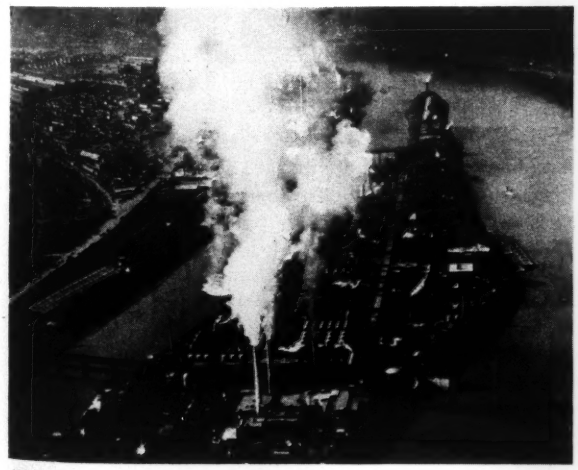
Slide 15 shows further improvement by increasing the pressure to 400 pounds.

Slide 16 shows the effluent when the spray pressure was at 500 pounds.

Based on the data obtained from plant scale operation thus far, it is evident that it is possible to operate the acid recovery process at maximum production rates with no pollution of the atmosphere by sulfuric acid mist.

The next two slides, 17 and 18, show aerial photographs of the acid fume stack effluent before and after the spray system was put in service.

Slide No. 17



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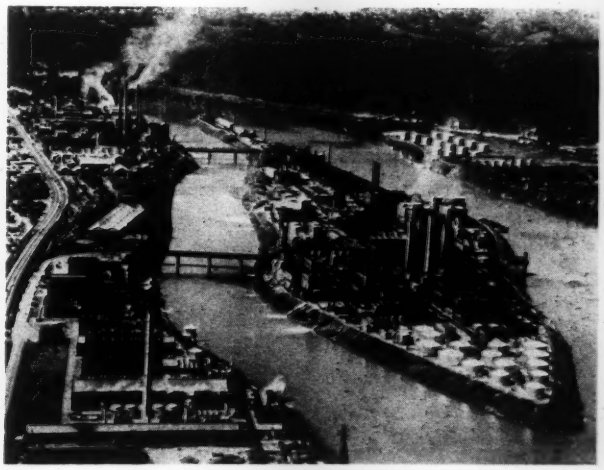

Cost of Operation

The annual cost of operation of the high pressure water spray unit is summarized as follows:

Amortization of investment	$14,000
Maintenance Cost	
Material	9,500
Labor and Expense	5,000
Power Cost	800
Fuel Gas	9,700
For a total of	$39,000 per year

This total annual cost must be increased to $60,000 per year if it is necessary to install a corrosion resistant duct to transfer concentrator effluent gases to a spray chamber, and if it is necessary to erect an acid fume stack to discharge the gases to the atmosphere.

The value of the sulfuric acid recovered, based on the cost for the equivalent amount of sulfur saved, and the value of the heat saving in the manufacturing process by the recovery of sensible heat from the waste gases amounts to $55,000 per year. The actual net operating cost is, therefore, $5,000 per year and amounts to $0.02 per ton of acid concentrated for the process concerned, or 1½ mills per 1,000 ft. of gas handled.

Fuel Supply Outlook

By George Lamb, *Manager of Business Surveys*
Pittsburgh Consolidation Coal Company
Pittsburgh, Pennsylvania

Within the next 10 years, and perhaps by 1958, coal-fueled electricity will take over many of the energy jobs now done by gas and oil. These projected uses alone will require an electric power load equal to one-third of the total electricity used last year.

In the decade ahead, electricity may surge forward in its greatest outburst of growth. Our nation merely has to extend the growth trend that has been experienced in energy during the past six years, for this opportunity to unfold.

From 1946 to 1952, the marketed production of gas doubled; demand for light oils increased 75%; and the use of electricity grew 72%. The same tempo of growth would require, by 1958, a supply of 16 trillion cubic feet of gas; 4.5 billion barrels of crude oil; and 800 billion kilowatt-hours of electric energy.

Onset of such demand will cause radical changes in the pattern of energy use due to the difficulties and costs of obtaining the basic fuel sources. Gas and oil will find it virtually impossible to sustain another growth of the scope experienced in the past six years. On the other hand, electricity, which can be generated from plentiful coal reserves, will have no such fundamental difficulties of supply.

The shifts in end-use energy will involve supplementing or replacing *residential* gas and oil applications with *electricity that to generate would require over 50 million tons of coal.*

For *industrial* uses, gas and oil would be supplemented or replaced *by over 150 million tons of coal,* most of which will be direct applications of coal and some will represent coal-fueled electric power.

The proved reserves of natural gas increased only 25% while the marketed production doubled. If this disparity continues, the growing demand for gas will have to be met with alternatives.

Electric power is a logical alternative and is already competitive with gas in a wider area than many realize. It will come in strong for hot water heating, cooking, certain industrial processes. Combinations of heating and air conditioning will increasingly take over segments of the heating market, particularly for new homes and in areas where temporary shortages of gas, as well as forthcoming price increases, provide an entry wedge.

Meanwhile, as oil demand mounts towards the projected 4.5 billion barrel point, the pinch on supply and higher replacement costs will force changes in oil refining and marketing. Use of distillates for space heating will start to fall by the wayside and electricity will compete for this home heating market. The production of residual fuel oil will be held to the technological minimum and industrial steam boilers now fueled by residual oil will again turn to coal.

Some authorities believe the rate of growth may not be as rapid as recently experienced. However, past tendency has been to underestimate energy requirements. Moreover, if energy needs fail to hit the projected increases in six years, they certainly will mature within 10 years. Even 10 years doesn't give us too much time to get ready.

Management Considers Air Pollution

By William F. Mitchell, *Vice President*
The Pennsylvania Salt Manufacturing Co.
Philadelphia, Pa.

Gentlemen, I appear before you today in the full knowledge that a great deal has already been written and said on the subject of air pollution, a subject as universal as man's activity. Much of this—in fact thousands of columns of it—have been the eloquent, often justified, and sometimes not too well informed objections of the victims of air pollution. A great deal of this material, full of wisdom, has been prepared by experts, some right here in this room, and already presented to you. The other day a man I know remarked, rather cynically, I thought, that the air pollution business consisted chiefly of a lot of experts telling each other all about it over and over again, year after year.

I am an executive of a medium size chemical company. We are in an industry which has had its share of air pollution problems. My company, the Pennsylvania Salt Manufacturing Company, has been grappling with these problems in various ways for some 103 years. In my job, I am the person in our management most directly concerned with such problems.

Perhaps for this reason it was suggested to me that I talk with you today on the subject: "Management Considers Air Pollution." I certainly cannot guarantee you that my talk will contain any new information. And because I am a representative of a management in a company constantly faced with this problem, my talk will be intentionally somewhat subjective. In other words, while I am attempting to interpret management's thinking on this problem to others, I am, at the same time, trying to define and clarify it to myself and others in management jobs.

Definitions Needed

To take off into this subject from this point of view, we need a few launching platforms, or definitions.

First, what is management and what is its general point of view? Management is responsible for the general direction and coordination of an industrial organization. It must be responsible for the provision of proper manufacturing facilities in the right location; for the selection, training and organization of people; for the economic aquisition of raw materials; for the transformation of these raw materials by the people and equipment into salable goods, and finally, for the sale of these goods. It must also be responsible for the general citizenship of its enterprise —in its community, its state and the country. Management must coordinate all these activities and assure their continuance with one primary goal—profit for those who have invested in the business.

I am not going to begin by shying away from the profit motive as the objective of American industry. I do not intend to sugar-coat this motive with a lot of high sounding side benefits of industry which often mislead people, in business and out, as to just what it is all about.

Let us understand each other: American industry is in business to make money. There are too many share owners —many right here in this room——who have benefited directly from the earning capacity of American industry. There are many others, some who have no other source of income, who are living on these proceeds. There are many schools, roads, public parks and other public benefits that have been paid for from taxes earned by industry.

And on top of this, the entire economy of America has grown on the ability of American industry to make profit. There are too many benefits from this one motive for me or any one else in American business to apologize for it or try to make it seem like something else. So let me repeat: American industry is in business to make money. This is the prime objective of any forthright management.

Now let us go to the second definition which is essential to this discussion of air pollution. In its manual on "Air Pollution Abatement," the Manufacturing Chemists Association gives this definition:

"Air pollution is the presence in the air of substances put there by acts of man, in concentrations sufficient to interfere with the comfort, safety or health of man, or with the full use and enjoyment of his property."

This is a sound definition. It defines the problem, is broad enough to cover it in general, and yet is concise enough to pin down exactly what we're talking about and to satisfy the technical mind. But each one of us tends to go from such a satisfying general definition to one more in our own terms. Such as this, from the management standpoint: Air pollution is a substantial product of industrial activity which is non-productive of profit. Having defined management's prime objective, we see that air pollution is a negative problem, an obstacle to the objective.

Management's Attitude

What then should be management's attitude toward air pollution and why is pollution primarily a management responsibility? These are the questions we must explore. We can begin with two generalizations.

First, since air pollution is, by MCA's clear definition, a nuisance, it can seriously reduce or eliminate the profit of an industrial activity.

Second, too often air pollution represents, at least in the chemical industry, some type of production inefficiency.

The articles contained in this issue of Air Repair represent the balance of those given at the Baltimore Annual Meeting. Authors wishing reprints should file their requests with Headquarters which will advise as to cost for the number of reprints desired.

The next step for management is to put this particular problem in focus, in proper proportion, and in this we need to consider the feelings and problems of all others involved and to enlist their help to our thinking. We also need to relate this one problem to many others we face in reaching our objective.

Waste is one of the major results of human activity. Wherever people gather they create some form of nuisance. In almost everything we do we create some disturbance for someone else. The bigger we are, or the more of us acting together, or the more active we are, the bigger the disturbance we create. In the simple matter of our everyday family lives we do this. We create noise, automobile fumes, garbage, dust, hazards for others. Singly or together, sometimes by great and purposeful effort and sometimes without even trying, we create ugly eyesores and, what is perhaps saddest of all, a great deal of human discord.

Living in Concord

Because of this unhappy aptitude of all mankind, the biggest problem of society is to learn to live together with the least possible discord. Because we recognize that we are all far from angels, civilized society sets up curbs to prevent any one person or group—and again I quote the MCA definition—from "interfering with the comfort, safety or health of man, or with the full use and enjoyment of his property."

Basically, we all recognize the need for this. It is one of the marks of the corporate maturity of civilized society. We accomplish this regulation formally through laws, courts, and regulatory bodies. We go further in banding together, in many types of organizations, to regulate our own activities. In addition, we apply and are regulated by the intangible but very strong force of public opinion.

All this boils down to one incontrovertible fact of life: No matter how worthwhile or profitable any enterprise, it will be curbed or eliminated if any part of its operation impinges too far upon the public welfare. And because our sense of justice proves that we believe we are our brother's keeper, I know that if I impinge too far upon the rights of my neighbor, even though he is not yours, you will come to his defense. He represents the public welfare we are trying to protect.

Air pollution is a case in point. What activities are its causes? A plant manager who is under severe attack because of the air pollution from his plant can become bitter when he lists them all. Just briefly, I would like to enumerate a few: Exhaust fumes from thousands of automobiles in any downtown section on a hot day; the odor and smoke from city dumps or garbage disposal units; the rising pollen count from many ragweed filled vacant city lots; the sun-blotting smoke pall from nearby forest or field fires; tons and tons of dust which may have been borne on the winds from as far away as the Sahara or a South Pacific volcano, and the ordinary smoke from the chimneys of thousands of homes. None of these is caused directly by industry and some not even by man, yet they are enough in themselves to make life unpleasant.

Smog in Ohio

I have a friend who worked a number of years ago on a newspaper in a small industrial town in Ohio. This town, which has two large steel plants, is set down in a natural bowl which somehow captures the air. During a wet winter the newspaper was getting many letters complaining about the smog caused by industry. They were about to begin an anti-smog campaign in the paper, and as a first step called the city smoke abatement officer. He asked them to wait a few days until he completed a report.

His report showed that nearly every home in the city was burning soft coal. After these homes, the biggest producers of fly ash were the three hotels and the city schools. The steel mills, which were chiefly electric furnace operations, were minor offenders. The newspaper reported the facts and the letters stopped.

All this may give some comfort to the plant manager or someone in my position, but the fact remains that most industrial operations, and specifically chemical operations, can pollute the air unless proper precautions are taken. The fact that someone else is causing air pollution never excuses us.

In the construction or operation of an industrial plant, we are forced, if we keep our main objective in mind, to weigh this problem of air pollution against many other problems. Air pollution, stream pollution, noise or some other nuisance may be inherent in any one of our operations. In one way or another, the methods of controlling or eliminating these nuisances cost money, which in some way must be paid from the gross proceeds of the operation or from some outside source. In other words, these control methods add to the cost of operation.

Added Costs

But there are other added costs we must also face. These include proper facilities for the comfort and safety of employees; shipping costs; office overheads; engineering and technical services; taxes, and a host of others. All these have to be squeezed in between the basic cost of converting raw materials into finished goods and the price the customer will pay. The sum of these costs sometimes will not fit into this narrow margin, and when that happens, unless the situation can be corrected, the industrial operation is doomed.

The abatement of a nuisance such as air pollution, is, in the strictest sense, non-profit producing. Viewing many operations from the standpoint of greatest short term economy, it is much cheaper to ignore this cost altogether. In former times, gentlemen, this was the solution to the problem. The industrial areas of America, England and Europe still show the results.

Why, then, are air pollution and its related nuisances primarily management problems? First of all, their control represents non-productive, and sometimes very costly, capital expense. Now we have to take a look at what this expense, or the absence of it, does to our operation.

Go back to one of the first facts of life. If an industry, no matter how profitable or worthwhile, impinges too far on the rights of its neighbors, it will be eliminated. Beginning with the outer limits of this drastic result, let's work back through the effects air pollution can have on an enterprise. First of all it will create a large number of complaints from those within the affected area. They can sometimes be temporarily calmed down by certain grandiose community relations gestures, such as the provision of a municipal park (outside the affected area, of course), or a donation of a new wing on the local hospital to take care of pulmonary cases. But such gestures are not only costly and must be repeated, they are like putting salve on a boil. They may temporarily relieve the surface manifestation, but the basic, internal cause still remains. The people will continue to kick. They don't want to go to the park 10 blocks away. They want to be able to sit out on their own porch in the evening.

Avoid Law Suits

At first they may be only vociferous, but their complaints can quickly become a costly counterirritant, simply in terms of time consumed and plant management's ulcers. When these complaints don't work, then the neighbors resort to suits. Without elaborating on this, I would like to pose a question to all management people. Which adds more to the cost of operation: $100,000 paid out in damage claims or a like amount spent in pollution control? The former usually results in the latter expenditure anyway.

On top of this, there are other results. If you are polluting the air in your area, the real estate values begin to drop. One solution is not to build too near properties where this may result, but many of us do not have this choice. Too often, these nearby areas are residential, and when the values drop too far, the area becomes a slum. The slum then breeds its own problems that are inevitably costly to the operation of the plant.

Then we have the problem of our own employees. Their health we must consider. But our employee carries our air pollution problem home with him. Every night he sees the curtains at his window and the linen on his bed gray with industrial smoke, and he knows how often his wife washes them. He sees what is happening to the paint on his own house and that of his neighbors. And this he lives with. What do you think this does to his morale and work efficiency?

Inefficient Operation

The very high-cost luxury of creating an air pollution nuisance can come up in other ways, too—sometimes more technical but nonetheless costly. As I mentioned earlier, too often industrial waste which causes air or stream pollution represents some type of operation inefficiency—the throwing away of products which should, in some way, be used. This is a continual challenge to all of us to improve the yields in our processes.

Very often one of the most serious costs of ignoring an air pollution problem is the great increase in the maintenance and upkeep required. As we know all too well in the chemical industry, the stack effluent which may mean a minor irritation to nearby residents can mean thousands of dollars in corrosion of our own equipment. This is one of our most serious problems and while protective coatings have been developed to a high degree, the elimination of the corrosive elements in the atmosphere is much cheaper in the long run.

The foregoing weighs the cost of pollution control against some of the results. There are other factors, but it all boils down to this: Control or abatement of a nuisance is always cheaper than ignoring it.

I say to every man now in industrial management or expecting to be in such management: The control of air or stream pollution or any other public nuisance is a definite cost of doing business. In one way or another, it has to be paid.

What To Do?

Having accepted this fact, the next problem for the management man is what to do about it. Research has solved many of the problems and is attacking others. The control of air pollution has become a big business in itself. The literature is full of excellent data. Engineers are available who are thoroughly competent to examine the problem and recommend the best and most economical solution. The equipment manufacturers themselves can be helpful.

Many of us have inherited problems in air pollution from existing processes. We are then faced with correcting or modifying these conditions. In most cases this is the more expensive solution.

In the chemical industry of recent years we have been going through a remarkable period of expansion and new construction. This has given our industry its best opportunity to clean up its own air pollution problems. The best solution is to engineer controls into the original construction of a plant or process. With few exceptions, our experience enables us to anticipate what they will be.

Once we keep this problem in mind from the beginning, we can use many different methods of solving it. Top management usually is aware of these methods. One example is plant location. Given a choice of two locations,

both reasonably equal in other respects, the one farthest removed from a residential area may be best and avoid future trouble.

Next, we can go through the entire operation planning to install control equipment right in the process. Engineers will recognize that such integration is almost universally less expensive than adding such controls after the operation has been built. In many operations a far-sighted engineer can solve many of his problems in the way he designs or in the materials of construction used without resorting to too much special control equipment. The more things like this he can do, the lower his control cost.

These are internal actions. However, this is a universal problem and we should be willing to take it to our friends outside the plant gate. One of our best friends in this case can be the municipal or state pollution control officer. He can give us a clear picture of the problem in our plant area and advise us on what regulations we must conform to. We can explain to him what we are doing in our own plant. We have thus brought in the public's representative to help us solve a problem which affects both us and the public.

Consult With Others

As a next step, I recommend that we consult with other industries in our area or in similar operation elsewhere. Since this is a problem which affects all industry, I believe all of us should be as helpful to each other as we can. Often our own plant will be blamed for a nuisance caused by an industrial neighbor. Fortunately, this practice of exchanging information on this problem is well regarded, and widespread.

Third, I recommend that we take our problem and its solution to the plant community. Someone once aptly defined public relations as "doing the right thing and then tactfully making your action known."

The fact is that the residents of our plant communities are not children; they are responsible, reasonable and intelligent adults. They know what our plant payroll is contributing to their welfare and, unless there have been other abuses, are basically sympathetic to our operation. When we have successfully solved our air pollution problem, we should let this be known. They will understand and will be grateful. Their sympathy for our consideration of them will repay us in many ways. There is one chemical manufacturer who does this in a dramatic way. His acid plant is located in the heart of a city. It is surrounded by beautifully maintained gardens and lawns.

Air Pollution Decalogue

To sum up these ideas, I would like to present an air pollution decalogue for management. I submit for your and management's consideration in general these ten points:

1. Control of air pollution and similar nuisances shall always be a part of process design.
2. Inadequate control methods will not be tolerated when better means are known.
3. Public laws and regulations governing nuisance control shall always be observed and control officers always treated with respect as the official representatives of the public.
4. Control mechanisms shall be in operation at all times when the plant or process is in operation.
5. With due respect to their efforts, mistakes inherited from your predecessors shall be corrected, and the fact that they were made before your time shall not be accepted as an excuse.
6. Find an answer to your nuisance problem before solving it by shutting down the operation or removing it and its payroll from the community.
7. Do not try to excuse or sidestep your own problem by pointing to the poor job being done by your neighbor, or other causes of pollution.
8. Don't procrastinate. Solve your problems as quickly as you can.
9. Do not try to cover up your faults by inaccurate, irrelevant or misleading records of operations and nuisance control.
10. Work with your neighbor on all pollution problems, because they all affect the community. If he has solved a problem, approach him directly about his know-how. Do not hire away his specialist.

I believe these points carefully followed will help all of us in our air pollution abatement efforts.

Performance of Coal-Burning Steam Locomotives

By G. W. Meredith, Master Mechanic
Norfolk and Western Railway Company, Bluefield, W. Va.

During the years of our last great war, and now during the postwar years, our country is experiencing an ever-expanding economy. The growth of our commercial and industrial position has been on a gigantic scale, and has served to augment the magnitude of our people's demand on transportation. It has been like a golden egg held before the airways and waterways, pipe lines and truckers to compete with the railroads as common carriers.

The railroads have continued to remain the backbone of our transportation system. To keep in the forefront, management has constantly demanded and received greater operation efficiencies, and, consequently, the inevitable turn toward more modern forms of motive power.

While many of our country's railroads turned to Diesel and some to straight electrics, the Norfolk and Western recognized the greater potential power yet to be yielded by modern coal-burning locomotives, and has pursued such a course.

In doing so, the N&W not only considered the design of the locomotive, but also the geographical location of the railway, maintenance problems, improved terminal and road facilities, and other related conditions directly contributing to efficiency, in order to arrive at the highest possible performance of the steam locomotive.

Fuel Is Significant

Another significant factor to name is the fuel which we use. In our case, as most of you already know, it is coal. To be located in the very heart of rich coal fields, as is the Norfolk and Western, where nature has processed an abundance of high quality fuel, which can be purchased at a comparatively low cost, can be a most determining point governing economy, and the efficient operation of the steam locomotive.

Still another factor, one which affects high operating efficiency, is the building of locomotives in our own shops. Since the year 1884, the N&W has been designing and building motive power. We have acquired new engines at relatively low construction cost. Our present manpower, and machine tools required to maintain and repair existing locomotives, also are capable of turning out of our shops at Roanoke, Virginia, new modern locomotives at the rate of two per month.

When we speak of the steam locomotive, we refer to modern reciprocating power as that which is equipped with roller bearing wheels under both engine and tender, high capacity boilers which permit steam pressures up to three hundred pounds per square inch, complete mechanical lubrication systems, cast steel bed frames, and improved counterbalancing.

The first modern locomotive built by the Norfolk and Western was the Class "A", No. 1200, turned out of Roanoke Shops in May 1936. Since that time, forty-three of this type have been built; the last one in 1950 at an estimated cost of $300,000. They were designed for both freight and passenger service and have proved very successful in the movement of heavy trains over relatively low grade territory.

The class "A's" are articulated, single expansion locomotives, with a tractive effort of 114,000 lbs. Their weight, engine and tender in working order, is 475 tons. They have a 2-6-6-4 wheel arrangement, and a total length, coupler face to coupler face, of 121 ft. and 9¼ inches.

The maximum drawbar horsepower development is 6,300 at 45 miles per hour. They are capable of sustained speeds in excess of 70 MPH where operating conditions permit. Tests have shown that maximum evaporation of the boiler is 14,000 gallons of water per hour and the maximum combustion of coal in the fire box to be seven tons per hour.

Mallet Locomotives

Other types of modern freight locomotives built in Roanoke Shops include the Y5, Y6a and Y6b. They are compound mallet locomotives with a 2-8-8-2 wheel arrangement. They are the heaviest and most powerful engines we have, and are frequently referred to as the "workhorses." They, too, have proved highly favorable to the coal service. Their starting tractive effort, with an improved intercepting valve, is 127,000 lbs. compound, or 160,000 lbs. simple. The simple position represents a 20 per cent addition in starting tractive effort and enables the locomotive to make successful starts on heavy grades, or under adverse conditions.

They are used in both slow and fast freight service in mountainous territory and, when operating conditions permit, can attain speeds of 45 to 50 miles per hour with tonnage trains.

At the present time we have 100 of these locomotives. The last one was built in Roanoke Shops in 1952 at an authorized cost of $300,000.

Records Established

These types of power have helped the Norfolk and Western to maintain high operating standards, and to keep pace with other leading railroads. Our locomotives, during 1952, made a record average of 162,495 miles between shoppings for heavy repairs. We also established a new record for the average gross ton miles per train hour on our system of 68,820.

But, like all other progressive industries, we too are looking forward into the future. Our shops and research laboratories are continually seeking the answers to greater power and improved design.

A dynamometer car, plus other necessary laboratory facilities, is employed extensively on the N&W to determine traction, thermal efficiency and all such performance characteristics as are desirable to know. On our drawing boards are plans calling for newer, more modern, coal-burning locomotives.

One such locomotive is the coal-fired steam turbine electric freight locomotive now being built. It will have an efficiency approximately twice that of conventional reciprocating steam power, and will be one of the world's largest single-unit locomotives. Its length with tender will be 161 ft. between coupler faces, will weigh near 600 tons and be rated at 4500 horsepower.

This locomotive is the combined development of Babcock & Wilcox Company, Westinghouse Electric Corporation, Baldwin-Lima-Hamilton Corporation and the Norfolk and Western Railway Company. The boiler is of the water tube type, natural circulation, having a capacity of 51,400 lbs. of steam per hour at 600 p. s. i., and 900-degs. F. The boiler is fired by a stoker similar to the conventional locomotive stoker, with steam jets to distribute the coal over a traveling grate. The design also includes forced draft, an economizer, an air heater and pneumatic controls for automatic operation.

Steam from the boiler will drive a non-condensing impulse type turbine which will be connected thru a set of single reduction gearing to a two-unit direct current generator. Current from the generator will drive the locomotive's twelve traction motors, one mounted on each axle of the locomotive. Provision is made for dynamic braking.

The locomotive is scheduled for delivery sometime this summer.

Contribute to BCR Effort

The N&W is also contributing to the project of Bituminous Coal Research Incorporated, for the construction of a pulverized coal-fired gas turbine electric locomotive. This project is sponsored by nine eastern railroads, five coal companies, and Bituminous Coal Research. The turbine is now under test at Dunkirk, N. Y.

This locomotive will weigh around 780,000 lbs. with all of the weight supported on four six-wheel trucks. It will have a rated shaft horsepower of 4200, with a starting tractive effort of 130,000 lbs.

Commitments favoring the coal-fired gas turbine were made last March 6th by Walter J. Touhy, President of the Chesapeake and Ohio Railway Company, who addressed the annual meeting of the Bituminous Coal Research Incorporated. He related that the efficiency of the gas turbine would be high and indicated that the project, when fully developed, would compete with, or even rate a little better than, Diesel power.

Millions Appropriated

Each postwar year the Norfolk and Western has appropriated millions of dollars for improvements. Grades and track curvatures have been reduced so as to allow the locomotive to operate at efficient speeds. Terminal facilities have been designed for modern straight line servicing, which enables the motive power out-of-service time, and the servicing man-hours, to be decreased by permitting better and faster inspection.

Such terminal facilities are now being constructed at my location in Bluefield, West Virginia. The installations include an engine service building, combined ash handling plant and engine washing platform, modern coal wharf and sufficient track layout to avoid needless locomotive movement and conflicting traffic.

The locomotive, after it has completed a scheduled run, is turned in on either of two inbound tracks by the engineman. From this location, the hostler takes over, and the locomotive proceeds thru the various stations until servicing is complete.

The first stop is at the ash-handling plant. Here, the fire is cleaned and ashes dumped from the locomotive ash pans into a hopper, where nozzles, supplying continuous streams of water, wash the ashes into a sluice trench, where they are lifted by a centrifugal pump to an overhead storage and de-watering bin, and later deposited in a cinder car.

During the ash cleaning process, there is usually ample time to fill the tender with water, after which the locomotive continues over the 140-ft. multiple-track washing platform for that phase of the work, and then directly to the engine service building.

Modern Service Buildings

The modern engine service building is 165-ft. long and 60-ft. wide. It has two tracks complete with comfortable pits. Illumination entails the most up-to-date fluorescent lighting and the building is heated by thermostatically controlled unit heaters and radiant heat coils installed in the floors of the inspection pits.

Drainage trenches, covered with cast iron grating, are located on both sides of each pit to collect water that may drip from the locomotive and also water used to wash the concrete floor. The trenches serve to keep the inspection pits dry.

Within ten minutes after the locomotive has entered the building, she is ready to roll along to the coaling station where as many as four different units of motive power can take water, coal and sand at the same time, and at one spotting.

In some cases this production line method of servicing is broken when it becomes necessary for the locomotive to move off to the engine house for periodic inspection, boilerwash or certain repairs beyond the capacity of the engine service building.

In most cases though, the time needed to completely service the engine and have her ready for the road is less than an hour. Such terminals at other points along the Norfolk and Western have been capable of servicing as many as 135 locomotives during each twenty-four hour period.

Recent improvements to our powerhouse included the use of an "electric eye" to detect excess smoke leaving the stack. It is located in the boiler breeching, and when excess smoke is being generated, the device automatically turns on a red light and sounds an alarm.

Burning Process

The combustion of coal used to fire a steam locomotive is dependent upon oxygen, and the igniting temperature of the fuel. Before actual burning occurs, however, the coal, with aid of existing heat in the firebox, must be broken down into its component parts, namely coke and gases. The coke consists of fixed carbon and substances contributing to ash, while the gases evolved are composed of hydrogen and carbon, most generally referred to as hydro-carbons. The relative amount of each constituent in the coal is indicative of the fuel's heat value.

The real burning process now is to keep the desired fire-box temperature and to unite the proper amount of oxygen with a regulated amount of fuel. If a sufficient supply of oxygen is present, the carbon and hydro-carbons will burn so as to receive full heat value.

It is very important that our firemen observe proper methods of firing locomotives. This has resulted in a minimum amount of smoke and a substantial saving of fuel. The average fuel consumption of road locomotives on our system, during the year 1952, was 93.9 pounds per 1000 gross ton miles—the lowest figure on record.

Locomotive crews are continually being trained in smoke prevention and motive power shop men receive reports concerning engines that are not steaming properly or make excess smoke due to some mechanical failure.

A careful study has been directed toward fire cleaning methods, grades of coal, draft equipment, fire brick that will sustain high firebox temperatures and can be maintained economically. The locomotives are periodically examined for such faults as leaky flues, flues closed with cinders, combustion chamber containing fine coal and defective superheater units or leaking side sheets, all of which can account for excess smoke.

We have smoke abatement committees located at the various terminals along the Norfolk and Western. They meet monthly to study the different reports on smoke or smoke violations and their probable causes. At times it has been necessary to take disciplinary action or even replace some employees who have failed to observe certain rules.

The following is the number of smoke violations observed and reported on the Norfolk and Western by city smoke inspectors in each of three cities served by us that have active smoke abatement ordinances:

In Cincinnati we did not have a single violation out of a total of 510 observations made.

Columbus reported a total of 14 violations out of a total of 3066 observations.

At Roanoke seven violations were reported. No record was made of the total observations.

Since comparable observations have been made, other roads operating in Cincinnati and Columbus have not equalled our record of smoke violations observed in relation to the total number of observations made. This is a case, also, that finds the Norfolk and Western the only road using coal-burning locomotives exclusively last year.

The N&W has been one of the world's greatest coal-carriers. During the year 1952, our shipments of coal amounted to 46,495,667 tons, and represented 72.5 percent of the total freight tonnage handled.

Our continued use of steam power to handle this freight is a sign of faith in coal and the territory which we serve. It is a faith in the fuel which accounts for nine-tenths of America's known reserves and may well again in the near future be set to challenge oil as a source of fuel for the country's powerful locomotives.

The Petroleum Industry Sponsors Air Pollution Research

By Vance N. Jenkins*

Any one who has been in the Los Angeles area during an extended period of smog, has smelled the odors arising at times along the Houston Ship Channel, and has flown over that great pall of coal smoke and dust which at times practically hides the ground from view from altitudes above about 5,000 feet in the area roughly bounded by the air lanes connecting Chicago, Boston, New York, Washington, Roanoke, Louisville and St. Louis, does not need to be told that air pollution in those sections of the United States has become a problem of the utmost importance.

For, to use the popular G. I. expression, "He has had it." He knows by firsthand experience that air pollution is real, that it is here now, and he wonders if it is not here to stay. And, if he has an analytical type mind, he is certain that it is going to get worse before it gets better.

He can see that there is nothing to prevent the situation becoming worse until a lot more basic knowledge on the true nature of it and its causes is acquired and the implications stemming from this knowledge are analyzed correctly and logical programs of air pollution prevention based on experimentally determined facts instead of mere opinions and fallacies are worked out and put into operation.

Now the air pollution problems in certain areas of the United States did not reach their present magnitudes by a process of mushroom-like, overnight growth. To the contrary, they arrived at their present status by a process of slow, gradual increase over a relatively long period of time, during which the population of the nation increased greatly. Coincident with the increase in population, there was, of course, an increase in industrial activity and an increase in the area of land under cultivation with an accompanying increase in the amount of finely divided soil exposed to the dust raising forces of the winds.

Gradual Change

But the average citizen was not aware of the gradual change occurring. Only now, when he realizes that there has been a change and that his children's children may never have the nostalgic pleasure of recalling the beauty of the American landscape as he remembers it when he was a child, does he become very much concerned about it. And when he does, the chances are that he is inclined to place the responsibility for the change solely on industry or its management.

But what is management? The management of an enterprise, a unit of industry, is merely a group of men, called executives, who, as the result of possessing certain extra abilities, have been selected to guide the operations of that enterprise.

*Executive Secretary, Smoke and Fumes Committee, American Petroleum Institute.

Aside from having the extra abilities which fit them to become a part of management, these men are basically no different than the average person who has been reared in contact with the advantages of modern civilization. Among other things, they, even as you and I, like to live in pleasant surroundings which have adequate supplies of clean, clear, water for drinking, sanitary and recreational purposes and lots of good old-fashioned clean, clear, country air for breathing.

The purpose of this paper is to describe the pollution prevention activities of the petroleum industry which have resulted from the recognition, some thirty years ago, by the executives constituting the managements of its various units, that water and air pollution would become a very serious problem in certain portions of the nation unless well-planned actions were taken to prevent it.

Unfortunately, most of the other industries and most civilian units did not heed this early warning. As a result, the situation has become so bad in many areas that both the civilian and industrial populations have already suffered great economic losses as well as great inconveniences. And unless the matter is viewed calmly and logically and appropriate measures devised to alleviate these situations, a great deal more economic loss and inconvenience is liable to be met within these same areas before relief is found.

Major Problem

Although the growing air pollution problem is of national concern, it is not a national problem in the true sense of the word. It is a major problem which is made up of many local problems, many of which, it is true, are quite sizeable problems in themselves.

But each is different from the others because in any particular area the topographical conditions, the climatological conditions, the meteorological conditions, the types of industry and its distribution, and the distribution and habits of the civilian population are unique to that area.

Each of these factors either influences the degree of air pollution resulting from the emission in that area of a given amount of a pollutant or is influential in determining the amount and type of pollution which will originate in that particular area.

Therefore, each area is unique with respect to the factors influencing its air pollution problems and its problems are of a local nature. Hence, the enforcement of a law or laws, irrespective of origin, whether of local, state or national, cannot be expected to solve satisfactorily all air pollution problems. In fact, a law which may be applied

satisfactorily to the air pollution situation in one area may even delay the alleviation of the situation existing in another area.

Panicky People

The worst thing that can happen, in many instances, is the hasty passage of a law or laws for the control of a given air pollution situation. For in many such cases their passage results from a panicky feeling that "there ought to be a law" and laws drawn for such reasons are likely to be poorly drawn and based on either insufficient or erroneous data.

But once a law is on the statute books, there is a tendency for those who were in such a panic to get it there to relax and wait for the miracle it was to bring about to occur. But, as a rule, nothing happens, for the mere existence of even a very poor law that is supposed to solve a problem tends to inhibit further thought on the problem.

And, unfortunately, in such cases, further thought is exactly what is needed. That is why that passing a law is, in many cases, the wrong way to start about solving an air pollution problem. And passing the wrong law can also often be the most expensive and irritating way to approach the problem as far as both the public and industry are concerned.

At the end of the First World War in 1918, the petroleum industry executives serving on the President's War Advisory Committee on Petroleum agreed that their cooperative efforts in behalf of the industry should continue. After considerable thought and discussion, it was decided to form a permanent organization which would be called the American Petroleum Institute. This decision was approved enthusiastically by the industry at large and by 1921 the organization of the association now known universally by the abbreviation "A.P.I." was completed and a General Committee on Pollution appointed.

Because the organization was new and the idea of a cooperative attack on pollution problems was new also, not a great deal was accomplished by this Committee during the first few years of its existence. A number of meetings were held at which the problems connected with the pollution of navigable and other public waters were discussed and several water pollution surveys were initiated.

Magnitude Clearly Defined

As a result of these activities, the scope and magnitude of the problems confronting the industry became more clearly defined to the Committee members and constructive ideas as to how they should be attacked began to emerge. For example, by 1928 a Technical Committee on Prevention of Pollution had been activated and by the following year this Committee had prepared a preliminary draft on an American Petroleum Institute Code of Recommended Good Practice in the Prevention of Pollution.

In 1928 the idea of organizing the American Petroleum Institute into divisions was approved in principle. Under this plan, the various activities of the industry were grouped under the Divisions of Production, Transportation, Marketing and Refining. This organization plan was completed in 1929, at which time each Division assumed responsibility for developing controls for the pollution which might be expected to occur as the result of the activities of the branch of the industry represented by it.

Under this plan, the specific assignments accepted by the Divisions were as follows:

(a) The Division of Production undertook to prevent stream pollution resulting from oil field operations by studying the problem of oil field waste disposal for the purpose of developing the information and techniques necessary to provide satisfactory treatment of such wastes.

(b) The Division of Transportation agreed to develop information necessary to work out methods for the prevention of the pollution of navigable waters.

(c) The Division of Marketing was given the task of devising procedures to prevent the pollution of public waters by oil escaping from marketing installations.

(d) The Division of Refining accepted the assignment of developing satisfactory methods for the disposal of refinery wastes.

Regulations

Over the years intervening since this organization plan was adopted in 1929, the industry interest in pollution prevention activities of the Division of Production has decreased greatly. This results from the fact that all of the oil-producing states have enacted laws which regulate the disposal of oil field wastes, and compliance with them is necessarily handled by direct contact of individual companies with the state regulatory authorities.

Although over this same period of time the Federal Government has enacted laws regulating the escape of oil to waters under Federal jurisdiction, the Division of Transportation committee which deals with the prevention of such pollution is still very active in assisting the Federal regulatory authorities in preventing pollution of navigable waters.

The Division of Marketing distributed a bulletin in 1930 on the prevention of pollution by the escape of waste oil from filling stations and terminals. Apparently, the current pollution problems of the marketing portion of the industry are either of no great importance or are being disposed of easily on the basis of techniques developed in the past because there is little interest at present in the pollution prevention committee activities of the Division of Marketing.

The articles contained in this issue of Air Repair represent the balance of those given at the Baltimore Annual Meeting. Authors wishing reprints should file their requests with Headquarters which will advise as to cost for the number of reprints desired.

The Division of Refining initiated work on its pollution problems on May 26, 1930, at which time its Committee on Disposal of Refinery Wastes was formed. The minutes of the first meeting of this Committee indicate that it assumed responsibility for the continuation of the program started by the former Technical Committee on Prevention of Pollution by stating that its purpose was "To collect, summarize and recommend for publication to the industry, information which will direct and promote good practice in the disposal of refinery waste, particularly in the design, construction, and operation of waste disposal equipment, to the end that refineries of the petroleum industry in America do not release wastes of any kind which may interfere with the interests of their neighbors or the public in general."

Another Committee

From the time of its organization in 1930, the Committee on Disposal of Refinery Wastes recognized that the air pollution problems confronting the industry would, in time, become of major importance. But, even as late as 1938, few refineries were located in areas where the air pollution they at times caused was viewed as an evil which could be corrected.

The majority of the people living near refineries either worked in them or were dependent upon their operation for a supply of customers with cash from refinery paychecks. It was an accepted fact that refineries at times emitted strange odors and clouds of black smoke and very little, if any, thought was given by the public to the necessity of their continuing to do so.

With the beginning of World War II, however, the situation began to undergo a change. The relocation of war industries brought large numbers of people into refining areas who were not interested in the petroleum industry. And since the refineries were there when they came, it was easy to persuade them that the growing air pollution problem was caused by refineries rather than by the new industries and the people who had moved in to man such plants.

Attitude Changed

This change in attitude first became evident on the West Coast which experienced the greatest increase in war time population. It became evident several years ago that, in addition to the technology of handling waste gases and dusts *within* refinery limits, it was desirable to acquire information pertaining to the composition of the air *outside* refinery limits since it was apparent that the air pollution in certain areas, said to be caused by refineries, might be due to other sources.

As a result, a new American Petroleum Institute committee has been formed to foster development of information relative to the true nature and causes of air pollution of a certain type. The details of the organization of this committee and of its proposed program will be given later, but first let us review the factors leading up to the decision to create such a committee.

As pointed out earlier, the population of the West Coast began to increase at a very great rate during World War II. This increase was particularly large in the Los Angeles area. And, accompanying the increase in population, there was a corresponding increase in the number of automobiles, trucks and buses, of home fireplaces, gas ranges, hot water heaters, of home furnaces and backyard incinerators.

There also was an increase in industrial activity, new industries being created and the ones already in existence, such as steel making, aircraft building, lumber working and petroleum refining, being greatly expanded. As a result, the frequency of the occurrence of an objectionable degree of air pollution also increased .

Conscious of the pre-eminence of Southern California as a vacationing paradise for the remainder of the nation, certain units of the public press began to wage a campaign designed to awaken the citizenry to the danger resulting from the possibility of the area losing its lucrative tourist traffic if the growing air pollution menace were not overcome.

Speakers who had been helpful in mitigating the air pollution problems in other cities were imported and they gave their opinions as to what should be done to alleviate the Los Angeles situation. A number of different committees were formed to investigate the situation and, as a result, it received much publicity.

Refineries Cited

This campaign reached a climax, as far as the petroleum industry was concerned, on December 11, 1946, when one of the leading newspapers devoted half of its front page to a reproduction of an aerial photograph of one of the local refineries and identified it as a unit of the industry responsible for smog.

That afternoon the petroleum industry executives formerly serving on the Refining Committee of District Five of the Petroleum Administration for War were called together. After thorough discussion of the political, economic, scientific, and public relations aspects of the situation, the group organized the Petroleum Industry Committee on Smog, the purpose of which would be to determine what substances composed Los Angeles smog, to what extent the refining industry was responsible for it, and what steps would have to be taken by the industry to reduce its contribution to it. Later it became the "Committee on Smoke and Fumes of the Western Oil and Gas Association." It is still active under this last name and has met regularly each month since its organization.

The task of determining the identity of the pollutants present in Los Angeles smog did not prove to be as simple a matter as it was thought it would be. Therefore, in order to return the industry's scientists who had been loaned to the project to their regular duties, the Committee in March 1947 hired an independent research institution to solve the problem for it. The then recently organized Stan-

ford Research Institute was selected for the job and, in April 1947, it began to assemble personnel, analyse the data already collected by the industry's scientists, and plan a program for the project.

Large Sums Appropriated

Since that time, the seven refining companies originally represented on the Committee on Smoke and Fumes of the Western Oil and Gas Association have paid out well over $1,250,000 in financing the basic research project and several smaller special related projects at Stanford Research Institute and for the services of technical men loaned to it before the decision was made to hire Stanford Research Institute.

As a matter of record, California State Assembly Bill No. 1, which is the enabling act providing for the formation of County Air Pollution Control Districts in the State of California, was signed by the Governor and became a law on June 10, 1947. The Los Angeles County Air Pollution Control District was formed under that law in October 1947 but the preparation of its budget, the working out of personnel requirements and the drafting of its rules and regulations were not completed until February 1, 1948, at which time it actually began to function on a preliminary scale.

Thus, the smog investigations financed by the Committee on Smoke and Fumes of the Western Oil and Gas Association had been in progress for nearly a year when the Air Pollution Control District began operations. Since that time, it is estimated that the petroleum industry in Los Angeles County has spent some fourteen million dollars for new equipment and the modification of existing equipment for the purpose of reducing air pollution.

It is now evident that a large portion of this money may have been spent unnecessarily, in that its expenditure resulted in no appreciable or noticeable reduction of smog intensity in the Los Angeles area. It also is evident that much more money may be spent unnecessarily by the petroleum industry if certain proposed rules and regulations for the control of the emission to the air of certain substances which may play no part in smog formation are put into effect.

Results Published

The results of the research conducted by Stanford Research Institute were published in three Interim Reports and several Interim Technical Reports which constitute very instructive and very interesting reading.

They present very clear descriptions of the unique topographical and meteorological conditions which are responsible for the relatively small amount of pollutants from the Los Angeles area creating a smog problem of the first magnitude.

They also point out the lack at the beginning of the project of analytical methods sufficiently delicate to determine accurately the minute amount of some pollutants present in the Los Angeles atmosphere and describe the development of ones suitable for the determination of certain important contaminants.

Experiments are described which were made with a synthetic smog for the purpose of attempting to identify the substance or combination of substances responsible for the eye irritation experienced quite frequently, both in Los Angeles and other cities.

Late in 1950, the Los Angeles County Air Pollution Control District accepted as proven fact a theory on the origin and nature of smog proposed by one of its consultants. This caused a change in the nature of the Stanford Research Institute program which, since that time, has been concerned largely with investigations designed to determine the degree, if any, to which this theory coincides with facts.

New Theory

The theory referred to is the one which postulates that the reduction in visibility, the eye irritation and the crop damage noted during Los Angeles smog periods are due to finely dispersed liquid droplets which are claimed to be formed in the atmosphere by the reaction of ozone with olefinic hydrocarbons.

The ozone, in turn, is claimed to be formed by the reaction of nitrogen dioxide with saturated hydrocarbons. Both types of hydrocarbons are assumed by this theory to enter the air chiefly as the result of the evaporation of cracked gasoline from refinery processes and storage installations. The nitrogen dioxide is said to originate by oxidation of the nitric oxide formed from the nitrogen and oxygen of the air whenever fuel is burned at a high temperature.

The work at Stanford Research Institute has shown that there are a number of apparent errors both in this theory and in its interpretation to account for the various phenomena associated with smog. As yet, no one has been able to name the substance or substances which may be responsible for eye irritation or crop damage and no one has isolated from smog any substance which has been shown to be capable of producing eye irritation or crop damage in the concentrations in which it was found in the air. Actually it appears that air diluted automobile exhaust gases after exposure to sunlight will come closer to giving typical smog-type eye irritation and crop damage than any other pollutant yet tried.

Regardless of this fact, the theory adopted by the Los Angeles County Air Pollution Control District has been widely publicized and similarly accepted as proven fact by a number of other air pollution enforcement agencies throughout the nation.

Its acceptance by such agencies indicates that preparations will be made eventually in other locations, as they are now being made in Los Angeles, to control certain types of hydrocarbon emissions which may prove to play no part in causing air pollution of the type known as smog. If so, such unnecessary control would result in large and unnecessary expenditures by the oil industry.

Therefore, the refining industry as a whole has come to the aid of that portion of it represented in the Los Angeles area and will take over the task of fostering the development of basic information on the nature of air pollution and attempt to determine the responsibility of the industry for causing air pollution which may exist in areas in which refineries are located.

This decision was reached at the Mid-Year Meeting of the Refining Division of the American Petroleum Institute in May 1952 in San Francisco, during which the formation of the Smoke and Fumes Committee of the American Petroleum Institute under the Chairmanship of W. L. Stewart, Jr. of the Union Oil Company of California was authorized. At the Annual Meeting of the American Petroleum Institute in Chicago in November 1952, this Committee was authorized to solicit the industry for a contribution of $250,000 to be spent during 1953 in financing a number of research projects designed to develop information on certain fundamental aspects of air pollution.

Data Obtained

The program adopted for the first year consists of about a dozen projects, some of which were selected for the purpose of obtaining additional data necessary to clear up uncertainties remaining in connection with the ozone-hydrocarbon theory of smog formation. This is in line with the firm belief of the Committee that accurate knowledge on a subject must be available before accurate decisions can be made.

If the data developed indicate that legislative control of hydrocarbon emissions is desirable, then the A.P.I. sponsored research will have resulted in supplying accurate information instead of theories and hypotheses, upon which such legislation may be based.

If the data indicate that the control of the emission of small amounts of certain type hydrocarbons is not necessary in that they do not enter into reaction with other constituents of the atmosphere to form harmful substances, then the passage of unnecessary legislation may be prevented thereby, at a great saving of time and expense, both to legislative and enforcement agencies and to industry.

For administration of its program, the A.P.I. Smoke and Fumes Committee has set up an Executive Committee of four members, an *ad hoc* Technical Advisory Committee of five members, and a paid, full-time Executive Secretary. One of the aims of the parent Committee is to build up centers of information on the new approach it is sponsoring to air pollution by distributing the research projects constituting its program as widely as is consistent with efficient spending of the funds available.

Therefore, in order to obtain information vital to decisions concerning the location of the various projects, the Executive Secretary has visited some twenty-five of the leading universities and non-profit research institutions throughout the nation.

On the basis of the information developed, which has been reviewed carefully by both the Technical Advisory Committee and the Executive Committee, a number of contracts for projects have been signed already and active work on them is under way. It is sincerely hoped that results obtained from the first year's program will be of such great interest that the industry will wish to continue it for another year or longer until the major problems involved have been solved satisfactorily.

Need Thorough Investigation

I would like to refer again to earlier statements concerning the need for thorough investigation and development of complete and accurate information on a given pollution situation before legislation designed to cover it is enacted and the fact that a law designed to improve air pollution might have a reverse effect if not properly and wisely drawn.

As an example of what has occurred in the past, let us review the history of sulfur dioxide control in Los Angeles County. Although the concentration of this gas has never been nearly as high in the Los Angeles atmosphere as in that over many of the Eastern coal-burning cities, many of the experts imported to advise on the situation were rather emphatic in their statements to the effect that if the sulfur dioxide emissions were reduced or eliminated, the smog and attendant eye irritation would disappear.

As a result, at the first meeting in December 1946 of the Committee on Smoke and Fumes of the Western Oil and Gas Association, one of its members was given the task of determining just how much sulfur dioxide was put into the air each day in the Los Angeles Basin. At the following meeting in January, 1947, he reported that, based upon the average sulfur content of the various fuels and the known amounts of each which were consumed in the Basin, calculations indicated some nine hundred and thirty tons of sulfur dioxide was discharged each day and that approximately four hundred and thirty tons of this amount was contributed by the oil industry, chiefly from the burning of sour fuel gases containing hydrogen sulfide.

Measures Planned

With this knowledge in hand, the industry immediately began planning measures to set its house in order. The various refineries had plants designed and constructed to treat hydrocarbon gases for the removal and recovery of the hydrogen sulfide contained in them.

Some of the refiners arranged to dispose of the recovered hydrogen sulfide by either pumping it through specially constructed pipelines or hauling it in special pressure tank trucks to existing chemical companies which converted it into sulfuric acid. Other refiners contracted for disposal of the recovered gas to a new chemical company organized to produce sulfur from hydrogen sulfide.

As a result of this program, which was initiated voluntarily before the Los Angeles County Air Pollution Control District was formed, the emission to the air of some four hundred tons per day of sulfur dioxide is prevented.

Now the Rules and Regulations of the Los Angeles County Air Pollution Control District state, in effect, that nothing discharged into the air, such as stack gases, shall contain more than 0.2 per cent by volume of sulfur dioxide.

If a stack does emit sulfur dioxide in excess of this concentration, a variance must be obtained in order to continue operation of the plant or process from which the stack gases arise.

When obtained, a variance must be reapplied for at six-month intervals at considerable trouble and expense and plans for continuing efforts to reduce the emission to within legal limits must be shown for the application to have any chance of being granted.

The modified Claus process which is used to convert hydrogen sulfide into sulfur is not economic when more than about ninety-five per cent of the sulfur in the hydrogen sulfide processed is recovered as sulfur. The remaining five per cent is burned and emitted with the stack gases as sulfur dioxide. The sulfur dioxide in these stack gases usually is from about 0.5 to 1.0 per cent by volume and hence is above the legal concentration in Los Angeles County.

There are two modified Claus process plants now in operation in the Los Angeles Basin and application for the construction of a third is pending. Together, the two plants now operating recover approximately one hundred and seventy-five tons per day of sulfur which would be emitted to the air as three hundred and fifty tons per day of sulfur dioxide if they were not in existence. Yet, because their stack gases contain approximately twenty-five tons per day of sulfur dioxide in concentrations above the legal limit of 0.2 per cent, these plants, to operate, must do so under a variance which may be withheld at any time. It would seem a wise law would encourage the construction of such scavenging plants, the operation of which results in a large overall benefit by making them a special case and permitting their operation under even more economic conditions, such as by discharge from their stacks of up to ten per cent of the sulfur in their feed gases as sulfur dioxide at concentrations of up to 1.5 per cent without the necessity, expense and nuisance of operating under the variance system.

As a matter of fact, the refiners supplying these plants with the hydrogen sulfide they use as feed could burn all of the sulfur these plants recover and emit it to the air as sulfur dioxide from their stacks at less than the legal maximum concentration of 0.2 per cent by volume. And they could save money by doing so. For all they would have to do would be to cease processing their sour gases for the recovery of hydrogen sulfide before burning them as fuel. The fact that they have not done so and have no intention of doing so is good evidence that the petroleum industry is managed by men who want to be good neighbors, by men who will go more than half way in cooperating with enforcement agencies in order to be good neighbors, even when the laws under which they operate are not believed to be wisely drawn.

Oil Industry Viewpoint on Regulatory Picture

By F. H. Hawkins
Pillsbury, Madison and Sutro, *Consultants*
San Francisco, California

Before discussing the details of the air pollution enforcement picture in Los Angeles, I should like to mention the setting which brought forth the law under which these regulations are promulgated. You are all acquainted with the peculiar situation in the Los Angeles Basin with its combination of semi-circular mountains and frequent temperature inversions which prevents the escape of air contaminants released in the Basin.

There is, however, another factor, in addition to the physical make-up of the Basin, which was (and still is) important. Here was an area which had been nationally and internationally glorified as the world's most desirable garden spot. But the picture of perfection was marred by a smog condition whose description did not fit well into Chamber of Commerce advertising literature.

Faced with such a situation, the people in this country invariably do one thing—we pass a law. If no one knows how to solve the problem we are facing, we pass the law anyway with broad statements of the purposes to be accomplished. We then create some administrative officer, board or commission with power to make detailed rules and regulations. Thus the real law is actually written by the administrator and only the general frame-work is supplied by the legislature.

Experimental Bill

This pattern was closely followed in the Los Angeles situation. The bill which was presented to the 1947 session of the Legislature was admitted by its draftsman to be experimental. Its sponsors frankly stated that they did not know whether the passage of their bill would accomplish the result they desired. But they had to do something.

The law is expertly drafted and, depending upon your viewpoint, is either about the best—or the worst—law that could have been prepared. Since the draftsman was a lawyer who didn't know any more about the cause of smog than I do, he prepared the toughest law he could, designed to permit the exclusion or reduction of all air contaminants, on the theory that if you stop all contaminants, guilty or innocent, you will certainly stop the guilty.

Why have a new State law at all? The law provides that, upon proper action of a county board of supervisors, the county is converted into an air pollution control district and the Board of Supervisors becomes the Air Pollution Control Board which runs the district. Since the district has the same boundaries as the county, and since both district and county have the same governing board, why did not Los Angeles County merely adopt any necessary county ordinances rather than this unique state law? The reason, as I understand it, is that the county counsel feared that the county's powers were insufficient to reach within the boundaries of incorporated cities located within the county. He thought that the creation of a district under state law would remove any question of the enforcement of the law within incorporated cities.

Withstands Constitutional Attack

It was a foregone conclusion that the Los Angeles Board of Supervisors would convert that county into an Air Pollution Control District as soon as practicable after the 1947 statute became effective—and—that is exactly what happened.

The law is expertly drafted to withstand constitutional attack. There are adequate provisions for notices and public hearings, and the draftsman went far beyond the usual provision for judicial review of any administrative action taken under the law. The law actually provides for a trial de novo in the county court and an independent determination of the reasonableness and legality of any such action on all issues of law, facts and opinions involved (Sec. 24,323). The law also contains a procedure for obtaining "variances" by which is meant the relaxation in favor of particular individuals who are unable to comply with the prohibitions of the law or regulations. A permit system is set up which permits the authorities to approve particular devices and equipment rather than permitting permittees to achieve required results by any means they desire to use (Sec. 24,264).

The prohibitions in the law are simple. They prohibit (first) any emissions as dark as Ringelmann 2, and (second) the emission of any material which would amount to a nuisance, using the broadest terms to define "nuisance." So far, the prohibitions amount only to a strict smoke abatement requirement and a broad, all-inclusive nuisance definition.

Discomfort Is Reason Enough

The real teeth in the law are found in the provision which permits the Control Board to make rules and regulations which will reduce the amount of air contaminants released whenever the Board finds that the air is polluted sufficiently to cause any discomfort or property damage to a substantial number of the District's inhabitants (24,262). Translated into terms applicable to Los Angeles, this means that so long as a smog condition is found to exist in that county, the Control Board may do almost anything to reduce air contaminants—whether or not the air contaminant to be reduced is proved to be a contributor to the property-damaging, eye-irritating, visibility-reducing air condition which is called smog. It is under this broad rule-making power that most of the District's work is carried on.

So far as the oil refining industry is concerned there are two principal programs of the district to reduce smog. The first was the sulfur recovery program to prevent emission of oxides of sulfur. In compliance with this program, refineries, which were not already doing so, have installed equipment to capture hydrogen sulfide. In the early days of district enforcement it was apparently thought by the enforcement officials that the sulfur recovery program would be a cure-all. After virtual completion of the program, however, the smog problem still remains.

Vapor Recovery

The second principal program is one of vapor recovery to prevent the escape of hydrocarbons from the storage of gasoline and petroleum distillates. This program is contained in the District's recently adopted Rule 56, which sets forth a time schedule within which tanks for the storage of certain petroleum products must be equipped with pontoon floating roofs or connected to vapor recovery systems. This rule is predicated upon the Haagen-Smit theory that smog is caused by the oxidation of unsaturated hydrocarbons in the high ozone concentrations of the Los Angeles atmosphere. The oil industry did not oppose the imposition of this rule, but there is substantial opposition to the statement which accompanied the rule. This statement is that seven or eight million dollars which will be spent to comply with the rule will be recovered by the industry by the curtailing of product losses.

California newspapers have carried rather glowing accounts of the beneficial effects which the District expects from the vapor recovery program. If the Haagen-Smit theory is sound—and this is a matter upon which I am not qualified to comment—and if the optimistic predictions of the benefit to be derived from the vapor recovery program are realized, then surely smog in the Los Angeles area will be materially reduced. But if this program accomplishes no more than the sulfur recovery program, what can the enforcement officials do? The force of a continuing public demand will undoubtedly require these officials to initiate a further campaign. And until the basic cause of smog is definitely known, such further compaign may be undertaken without any assurance that its completion will solve the problem.

General Public Indignant

A review of the District's Rules and Regulations discloses a complete absence of any reference to what are believed by many to be major contributors to smog—the automobile and the backyard incinerator. There are undoubtedly as high concentrations of automobiles and trash-burning incinerators in Los Angeles as in any city in the United States. Of course, any action relating to automobiles or incinerators would involve millions of people, whereas there are relatively few industrial establishments—and any enforcement program must be politically practical. In this connection it must be admitted that the general public has shown little interest in a scientific investigation of the cause of smog, but rather has voiced an indignant demand that smog be eliminated. In this situation it is only natural that officials are prone to adopt theories which hold industry primarily responsible and to devise prohibitions aimed at the few rather than the many.

Air Pollution Control Measures at Baltimore Refinery

By Norman E. Fawley
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Baltimore, Md.

This presentation is of an altogether different nature than those you have just heard, which were pretty much of a general nature. What I should like to discuss are the problems of a specific oil refinery in a specific location. Except for topographical features and nearness of residential area the problems are undoubtedly common to oil refineries. In order to understand the situation, a little background information should be helpful.

The throughput or capacity of the Esso Baltimore refinery has grown from several hundred barrels a day until now approximately 60,000 barrels of crude are processed each day. From this crude a variety of products are produced—gasoline, kerosene, fuel oil, jet fuel, and asphalt to name a few.

Crude oil, the raw material, consists essentially of a mixture of many different hydrocarbon molecules with sulfur compounds. To separate and refine these components into useful products requires the expenditure of tremendous quantities of heat. This heat is supplied by burning some 3500 gallons of fuel oil per hour and an almost equivalent amount of combustible gas.

Burning of this fuel is accomplished in twenty boilers and furnaces, located throughout the refinery. When you stop to consider that fuel consumption amounts to 7 to 8% of the crude processed it becomes obvious that combustion control is an important factor with respect to potential air pollution.

Location of Refinery

The refinery is located on the Northwest Branch of the Patapsco River in the eastern industrial area of Baltimore. Oil has been processed on the refinery site almost continuously for the past 60 years. Over the years a residential area has sprung up until now a densly populated area is located not more than several hundred yards from the refinery on the north side. This residential area is uphill from the refinery.

As a result of expansion of capacity over the years in a rather restricted area of only 184 acres the refinery is very compact and the points of flue gas discharge rather concentrated.

Many other industries are located south and east of the refinery and further aggravate the situation by making it difficult to single out any one particular source of pollution.

As was experienced throughout the nation, the last several years have brought a sudden increase in the number of atmospheric pollution complaints. The increased complaints are not due to a change in refinery operations or a change in weather conditions but are rather the result of increased concern and awareness on the part of the general public.

In order to continue being a good neighbor, the Baltimore refinery initiated an extensive study of the existing pollution situation. Results of this survey indicated that combustion operations constitute the major portion of the problem and that miscellaneous process operations involving complex compounds may also be potential sources of pollution. The refinery deals with such materials as H_2S, light hydrocarbons, acid mist, asphalt oxidizing products, and mercaptans. Combatting pollution of the air with such materials has been a continuous effort over the years.

Personnel Organized

In addition to making the survey of the situation, key personnel were organized to handle and investigate pollution complaints at any time of night or day. Responsibility for this work is centered on the supervisor who also handles waste disposal and water pollution control activities. We also have a cooperative arrangement for handling complaints.

The Consolidated Gas, Electric Light & Power Company of Baltimore has a group of telephone operators set up to receive calls at a very high rate and have educated the public in general to report gassy odors. The Gas & Electric Company notifies both the City Health Department and our refinery management whenever a group of complaints come in.

We are in a position to promptly inspect the area from which the complaints arise and simultaneously determine if there has been some accident or failure of equipment in the refinery which might have contributed to the condition reported.

Let's get back to the study of the situation. Recognizing that prompt solution to the overall problem was desirable, the next step in our program involved studying various methods to reduce atmospheric pollution. Of a large number of alternative projects, six were selected as a basis for the current air pollution abatement program.

Money in the amount of about $320,000 has been approved in the past two years for the installation of these projects, not including operating cost. Please understand that there have been other considerable expenditures which abate pollution. These expenditures were not included because they were not primarily pollution control measures. In other words, we are investing $320,000 plus operation expenses for projects which are purely for pollution abatement.

Refinery Flare

The first project we would like to discuss is the injection of steam into the main refinery flare as a means of minimizing soot and black smoke emission. You probably have seen the flame burning from stacks or elevated structures at all oil refineries. This flare represents a large safety valve for the refinery.

Any units in which light hydrocarbons are processed or used are all designed so that their safety valves and other gas losses discharge to the main flare. When the gas rate reaches a very high level, incomplete mixing of the gas with air prevents complete combustion and, hence, the flare smokes considerably.

The gas rate is approximately 60,000 CFH. This offers a very unsatisfactory picture of the refinery and can be regarded as an intermittent source of air pollution. In order to reduce black smoke emission, a steam line has been inserted into the flare approximately 3 feet from the top. It has been demonstrated that injecting approximately ½ of a pound of steam per pound of gas will successfully eliminate what we call "trailing" smoke.

Remotely controlled steam injection facilities have been installed to eliminate smoke when flaring up to about 100,000 CFH, which is equivalent to that handled by one of the larger compressors at our gas compression plant. Let us discuss the effect of injecting 0.5 lb. steam/lb. of gas during the same flaring period. You will note that in addition to correcting the smoke production, the addition of the steam makes the flame much shorter.

We have very recently installed a complete and complex group of instruments to make the injection of steam fully automatic, thereby eliminating the human element in applying the steam when it is needed. We believe that this system is now adequate for control of black smoke emission from the flare.

Smoke Control Facilities at the Boiler House

The next topic is not particularly unique or novel to the petroleum industry but is merely mentioned in passing. Smoke density recorders and indicators have been installed on each of the five boilers at the main boiler house. When the smoke density approaches a value of 2 on the Ringelmann chart a bell rings and a light flashes warning the fireman of upset conditions. The warning permits prompt action immediately by changing furnace conditions. The slide merely illustrates the control panel for one of the boilers and shows the smoke indicator recorder which actuates the alarm system.

Fuel Gas Surge Drum

Also being installed at the boiler house is a fuel gas surge drum. Refinery gas is produced at many of the process units and consists essentially of hydrogen, methane, and ethane. Since recovery of these products in marketable form would be prohibitively expensive, facilities are provided to burn them under process furnaces and at the boiler house. The slide shows a simplified diagram of the gas burning system.

Operation of the refinery producers of gas is continuous and since no facilities are available to store gas it is necessary to consume the gas continually at a rate equal to the rate of production.

Excess production necessarily means flaring. Constant pressure in the refinery gas burning line is maintained by control instrumentation which allows surplus gas, not consumed by process furnaces, to spill into the boiler house fuel gas system for consumption. Since considerable fluctuations exist in production and consumption of fuel gas to and from the line, pressure of gas at the boiler house varies from 3 to 35 psig.

This variation in pressure is rapid and continuous. Despite use of modern combustion control instrumentation on the boilers, supplementary fuel oil firing cannot be sufficiently controlled to compensate for such gas supply fluctuations while meeting varying steam output requirements. Consequently, periods of overfiring result and improper combustion conditions cause smoke emission from stacks.

To preclude continuance of this condition, it was decided to provide surge capacity in the boiler house gas system to dampen effect of varying gas supply. The proposed 10′ x 60′ pressure vessel shown on the diagram will increase the volume of the system by ninefold, and as a result, the present variation of 16 psi from the average pressure of 19 psig will be reduced to less than 2 psi from the average. Installation of this drum will materially reduce smoking of boiler house stacks.

Floating Roofs on Crude Storage Tanks

The storage of crude oil and its derivatives requires extensive tankage—some 200 tanks ranging in size from several hundred barrels to 100,000 barrels are in use at Baltimore Refinery When crude is pumped into a conventional fixed roof type tank the vapors are gradually displaced to the atmosphere.

In the floating roof tank the vapor space is eliminated and therefore when oil is pumped into the tank the roof merely moves up on the liquid surface. In some cases these vapors consist of odorous compounds which may give rise to complaints from individuals living in the proximity of the tank field. To eliminate this source of pollution it is planned to replace the cone roofs on three crude tanks

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with floating roofs. All of our sour crude will be handled in floating roof tanks. This work is planned for completion within a year.

Asphalt Fume Disposal

Asphalt is the high boiling residue left after distilling certain types of crude oil. Different consumers of asphalt require varying properties in their particular grades of asphalt as determined by the use to which the asphalt will be put. For instance, the asphalt used in house roofing materials is a very hard brittle material produced by blowing air through hot liquid asphalt.

As the air leaves the hot asphalt it contains oil vapors and may contain malodorous gases from the asphalt. Release of these odorous materials is objectionable and irritating to the nose and throat. Spray chambers have been provided through which the spent air passes countercurrent to a water spray. The water is capable of reducing these fumes considerably but has not proved to be entirely effective. The next slide shows the reduction in visible vapor emission brought about by water spraying.

In order to further reduce odor emission from the oxidizers it is planned to install a fume furnace. Fumes from each oxidizer will be piped to the burner and subjected to high temperature oxidation. Similar facilities have been installed at various other domestic refineries and prove to be very effective in eliminating the undesirable odor characteristic of asphalt oxidation.

Acid Hydrolysis Scrubbing Facilities

Sulfuric acid is used in the chemical treating of heating oil and gasoline components to improve the quality of these products and remove undesirable sulfur compounds. The acid and entrained hydrocarbon are then sent to vessels for separation and recovery. Separation of the acid is done by adding water and blowing the resulting mixture with air.

The effluent gas is scrubbed with salt water in a countercurrent scrubber prior to release to the atmosphere in order to remove SO_2 and acid mist. This system has been intermittently overloaded.

We have installed additional eduction capacity and provided larger fume lines to the scrubber to greatly increase the scrubbing capacity. It is expected that the improved facilities will remove all objectionable materials from the effluent.

In summary, here is a list of the projects I have reviewed. You will note that we are already operating three of the items. Excepting the asphalt fume furnace, the remainder should go into service this year. Upon completion of these projects we expect to be in a satisfactory position with respect to air pollution.

Project	*Pollutant*	*Status*
Steam to Flare	Smoke	Operating
Boiler House Smoke Control	Smoke	Operating
Fuel Gas Surge Drum	Smoke	Under Construction
Floating Roof Crude Storage	Sour Gas	Construction this year
Asphalt Fume Disposal	Odorous Fume	Engineering
Acid Fume Scrubber	Acid Mist	Operating

Air Pollution Planning and Zoning

By Benjamin Linsky, *Chief Smoke Inspector*
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City of Detroit, and
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Detroit Metropolitan Area Regional Planning Commission

This discussion will cover only a few points. It is intended to be stimulating rather than definitive.

First, that air pollution is a major factor in the planning work that is reflected in zoning.

Second, that air pollution control agencies, by working closely with planning agencies and zoning enforcement agencies, can increase the effectiveness of their service to their communities.

Third, that different levels of different kinds of air pollution have different legal status.

Fourth, that the new concept of Performance Zoning, as opposed to Specification Zoning, poses a challenge to air pollution control engineers.

These four points will, in some degree, be illustrated by experiences in and around the City of Detroit.

It is certainly not necessary to define the words in the title of this paper. But, in order to clearly distinguish the terms, it might be mentioned that Zoning is one of the tools produced by Planning. It is the tool which establishes public, legislative limitations on the use of each parcel of land. Thus Zoning is different from Private Restrictions, which establish private contract limitations on the use of land. A further distinction is that zoning violations are usually enforced by government agencies through criminal courts, whereas Private Restriction violations are usually interpreted and enforced by private persons through civil courts.

Study People's Wishes

Planning includes the process of studying the wishes and resources of the people, services and properties of a community or area and the development and promulgation of patterns of action that appear, to the planners, to be needed by the community or area.

Air pollution is considered to be any man-made unwanted contamination of the atmosphere.

In the process of planning, it is well recognized that one of the reasons why residences and some industries should not be too close to each other is that some industries have either not learned how, or have not been accustomed to controlling their air pollution. For the same reasons, it is recognized that some types of industries should not be too close to other types of industries. (It is easy to recognize that a coke oven battery should not be close to a precision machine shop. The uncontrolled sulfurous gases and coke dust are detrimental to the machinery and production of a precision machine shop.) It is apparent that when good air pollution control enforcement work is done, the conflict between industrial and residential property use is minimized.

The terrain, prevailing winds and air stability are factors governing the dispersion of atmospheric contaminants that should be considered by planners in establishing patterns for the zoning of land.

At the present time the Detroit Metropolitan Area Regional Planning Commission is completing the design of a Master Land Use Plan for an area comprising 3½ counties. Although the heavy extractive industries, such as cement plants and steel mills, must of necessity be located along the waterfront, upwind from the Detroit area in the prevailing wind direction (the worst position, from a pollution dispersion viewpoint), full consideration has been given to the air pollution factor in planning an isolation of this heaviest industry area, as well as other industrial areas. Residential areas are planned to be upwind from these other industrial areas in the region, well buffered by non-residential areas from the next upwind industrial areas. In the Detroit area, fortunately, winds other than the prevailing Southwestern, are quite brisk and generally free of deep temperature inversions.

Corktown Redevelopment

The Detroit City Plan Commission is considering the redevelopment of a part of the city called Corktown, which is a very old, mixed occupancy section in the heart of the city. This Commission in carrying out the policy of Mayor Albert E. Cobo has been planning to restrict the new land use in this section to those industries which will not affect each other or the downwind heart of Detroit with air pollution. Thus such clean trades as clothing manufacture, precision machining, and printing can find comfortable plant locations.

The agencies that carry out the work of air pollution control, planning, and zoning enforcement can, by working cooperatively, make each other's work easier and more effective, with less confusion to land users. The Detroit Smoke Abatement Bureau has, for several years past, deliberately and conscientiously sought the aid of, and furnished technical assistance to, the related agencies. We have membership on the Land Use Committee of the Detroit Metropolitan Area Regional Planning Commission, and thus guide the air pollution considerations of meteorology as well as specific questions such as how far away from a cement making plant housing should be

required to stay, (This concept that industry should be protected against encroaching residences is gaining wide acceptance.)

Check with Building Inspection Bureau

Similarly, the Smoke Abatement Bureau furnishes technical recommendations to the Detroit City Plan Commission to assist them in determining what special restrictions they will place when granting permission for certain special kinds of land use, such as junk yards, smelters, and acid plants.

Further, the Smoke Abatement Bureau works closely with the Building Inspection Bureau of the Department of Buildings and Safety Engineering, which enforces the Zoning Ordinance. Several times, the Smoke Abatement Bureau has found that air pollution violators emitting excessive dusts, gases, or fumes, were carrying on industrial operations that were prohibited by Zoning, but had not yet been caught up with by the Building Inspection Bureau. Similarly, the Building Bureau has referred new air pollution problems to the Smoke Abatement Bureau.

One more agency, the Detroit Board of Zoning Appeals, utilizes data from the Smoke Abatement Bureau to guide its decisions where air pollution is a factor. The Appeal Board refers the air pollution problems it learns about in its public hearings to the Smoke Abatement Bureau. The Zoning Appeals Board has the authority to permit nonconforming land uses to be extended, if the result is not detrimental to the neighborhood. Sound air pollution information is helpful in guiding some of these decisions. For example, the question was asked whether dust from a buffing and polishing operation could be controlled so it would not be nuisance to an adjacent home. The answer was available from the Smoke Abatement Bureau.

Various Legal Considerations

Just as there are different degrees of air pollution, as well as different kinds of air pollutants, there are different legal considerations of air pollution. While this discussion is not definitive it can be pointed out that a pollutant may be detectable, detrimental, and/or a violation of an air pollution law. This can be illustrated by considering hydrogen sulfide. At extremely low concentrations, the odor is detectable. If this barely detectable concentration occurs only a few times a year, it may not be detrimental to a residential neighborhood. The significance of the phrase "detrimental" is that many zoning control agencies are required to consider proposed land usage and to prohibit a proposed usage if it is judged to have a detrimental effect on a neighborhood. As to violation of an air pollution law, emissions of hydrogen sulfide would violate Detroit's ordinance if it caused property damage (such as darkening lead base house paints) or caused illness (and H_2S is a very dangerous gas), or was offensive (and in Detroit, offensiveness of an odor is determined by having several Bureau members make relatively unbiased determinations).

The fourth point to be covered is the concept of Performance Zoning versus Specification Zoning. In Specification Zoning, it is customary to control land use by listing specific types of industries that can and that cannot use a specific plot of land. Thus slaughter houses, rendering plants, fertilizer plants and asphalt refinery plants are usually relegated to the remotest pieces of land, whereas bakeries, dry cleaning plants, and plating plants are usually permitted near residences.

From an Air Pollution Control Engineer's viewpoint, such specified distinctions are arbitrary and out-of-date. For example, a poorly maintained dry cleaning plant can emit odors that are offensive for blocks, whereas a modern rendering plant, with proper controls, can operate so that it is undetectable 200 feet downwind. The newer concept of Performance Zoning being developed by O'Gara, Williams and others, proposes that industrial land use be restricted on the basis of how well it can control its troublesome aspects.

Thus a plant, regardless of what it produced, would be permitted to occupy a given site as long as it did not emit more than X smoke, Y dust, and Z gases (so far as air pollution is concerned). It might be permitted to occupy another site, closer to residences, if it emitted ½X smoke, ½Y dust, and ½Z gases. In effect, the Zoning Ordinance can contain air pollution control provisions which vary with the neighborhood.

This raises a challenge to air pollution control engineers to learn and publish more about the specific effects of specific concentrations of specific pollutants, and to learn and publish more about the relationships between location of the source of emission, emission velocities, mass rate of emission, physical characteristics of emissions, micrometeorology, and concentrations at various distances.

The Planning and Zoning authorities have indicated that it would be more equitable to regulate land use by spelling out what performance specifications an industry should meet with respect to its neighbors. At the present time, such performance specifications must include the broad judgment phrases like "offensive, unclean, etc."

In summary, I have not been definitive, but have attempted to discuss four propositions:

1. Air pollution is a major factor in planning and zoning.
2. Air pollution control agencies, by working with planning and zoning control agencies, can increase each other's effectiveness for the community.
3. There is a different legal status for different levels of different air pollutants—detectable, detrimental, and violations of air pollution law.
4. Performance zoning is more rational than specification zoning, but requires a higher order of technical skill by air pollution control specialists.

Some Phases of the Occupational and Atmospheric Pollution Programs of the Republic Steel Corporation

By J. W. Fehnel
Republic Steel Corporation

In my thirty-odd years' experience in this work, it has always been my good fortune to have been associated with companies that were desirous of carrying on their work in a safe and healthful manner, not only for the benefit of their own employees, but as good neighbors where operations were located in an area zoned for industry, but which also happened to be a residential area.

It is quite true that with the high degree of industrial activity present throughout our nation in the last fifteen years, the inevitable smoke and dust could not be entirely controlled. However, the degree of nuisance resulting in any given situation must not be considered on hearsay or a political effort to rabble-rouse some supposedly offended home owners, but on a factual scientific basis, leaving no guesswork to the actual conditions found.

In my years of association with many companies as an industrial hygienist, I believe I am safe in saying that Republic Steel Corporation was the first to set up an industrial health program to eliminate and prevent industrial health hazards.

In 1933, this Corporation, realizing the necessity of providing safe and healthful working environments for all of their employees, placed added stress on their active safety program and, under the direction of Mr. Robert H. Ferguson, developed one of the first complete industrial health programs in the country. This program was set up prior to the inclusion of most occupational disease coverages under workingmen's compensation laws.

Combating Silicosis

While with the National Safety Council, Mr. Ferguson had been associated with the late Dr. C. O. Sappington, and jointly they developed a number of scientific procedures in good industrial health practices. One of their major activities was directed toward combating silicosis in the heavy metals and other industries. It was, therefore, only natural, in laying the ground work for Republic's Safety Program, that Mr. Ferguson incorporated industrial health. While the two are so very closely related, their interrelated functions are often overlooked.

In 1935, I had the opportunity to cooperate with Mr. Ferguson in making the first comprehensive industrial health survey (of the Buffalo District) of this corporation. This survey, taken in the Buffalo District, embraced not only the evaluation of health hazards associated with the manufacturing operations, their extent and severity, but also the application of sound and practical corrective measures.

The survey so successfully pointed up possible health hazards and recommendations for their control or elimination, that Republic's management ordered similar surveys to be made of all their mining and manufacturing operations. A program was set up to survey each district periodically on a two-year schedule, so arranged as to take into consideration the seasonal variations.

Periodic Surveys

The periodic surveys, which have been continued since their inception in 1935, cover every department and every type of operation of the plant undergoing study. (Such detailed surveys reveal any changes in system and process and not only evaluate the associated potential health hazards but often uncover unsafe working practices and laxity in housekeeping.)

Even when the findings are negative, the tests are repeated on subsequent surveys. It has been found that a series of negative results covering an extended period of time can be of extreme value in reviewing claims of impairment of employees' health.

In making these health surveys it has been Republic's practice to employ the approved techniques used by Federal and State agencies to permit comparisons with findings in their health surveys. In reporting the findings of such a health survey, conclusions and recommendations are based primarily upon checked findings, and not simply upon visual observations or hearsay.

In recommending controls, it has been a fixed policy to avoid temporary measures, such as prescribing use of personal respiratory protective devices where applied exhaust or ventilation will better remove or efficiently dilute the offending dust, fumes, or gas. Respiratory protection is used only when other permanent control measures are not applicable, or when the exposure is isolated and of short or intermittent duration.

A copy of the survey report is sent to the plant manager accompanied by a letter calling attention to the conclusions and recommendations. When corrections have been provided, their efficiencies in controlling the determined health hazard are evaluated.

Complaints

Employee complaints receive management's earnest consideration and if investigation warrants, a health survey is conducted. The findings may indicate the necessity for further study of similar operations and exposures in other plants of the corporation.

A typical example of such a study was made between 1943 and 1948 to evaluate the potential health hazard in the use of sodium fluoride as a mold addition in the making of rimmed steel. The findings showed that no decomposition products, such as free fluorine or hydrofluoric acid were dispersed into the atmosphere and that the concentrations of sodium fluoride dust mechanically dispersed, while being intermittent and of short duration, were well below the accepted threshold limit.

However, in order to reduce the mechanical dust dispersion in the mold addition of sodium fluoride, the material was purchased packaged in glassine bags of two and four ounces in weight. These bags were plainly marked designating the contents which, of course, greatly increased the cost.

The findings of this study were convincing that no health hazard accompanied the use of sodium fluoride as a mold addition. A similar study made by the City of Cleveland Industrial Hygiene Bureau substantiated our findings.

Despite such conclusions, in 1947 the United Steelworkers of America (CIO) requested Republic to allow the U. S. Public Health Service to make a health study and report the manner in which sodium fluoride was being used as a mold addition, contending a health hazard existed.

An agreement was reached between representatives of the United Steelworkers, the U. S. Public Health Service and Republic, and field work was conducted between January 7 and February 8, 1948, in four of the Ohio plants of the Corporation.

Medical examinations were made of 350 males, of whom 187 were from two plants using sodium fluoride, 63 from a plant in which the use of sodium fluoride had been discontinued and 100 from a plant that never used sodium fluoride. The medical study included a detailed occupational history and a record of present diseases, operations and injuries.

Present symptoms were recorded with a special emphasis on initiative effects of fume. A complete physical examination was performed with attention directed toward any evidence of lens opacity and inflammation of the mucous membranes of the eyes, nose and throat.

A 14 by 17 inch X-ray of the chest was taken of each worker as well as an X-ray of his left wrist and forearm. Urine was examined for albumin and sugar. Red and white blood cell counts, hemoglobin determinations, serologic tests for syphilis, and leucocyte differential counts were made from the blood of each individual. A clinical oral examination was made of each of the 350 employees.

Samples Collected

The environmental study involved the collection of dispersed fumes and gases. A total of 149 air samples, 16 settled dust samples; and 9 control samples were collected. These were analyzed for fluorine, total fume, oxides of iron and manganese. X-ray diffractions were made of fume and dust, and nine samples examined for their fluorine content. The weighted exposures to sodium fluoride ranged from .4 milligrams to 2.2 milligrams per cubic meter of air.

The detailed study is given in Public Health Bulletin No. 299, "Health of Workers Exposed to Sodium Fluoride at Open Hearth Furnaces." The following statement appears as the second paragraph on Page 2 of this report:

> "In light of present information such concentrations of sodium fluoride would not be considered hazardous."

On the same page, under Conclusions:

> "When sodium fluoride was added to the molten steel in the molds or ladles, the compound was dispersed, without chemical change, into the working atmosphere. The weighted exposures of the workmen were not great enough, in the light of present information, to indicate any probable hazard or chronic toxic effects."

Independent Laboratory Employed

During the early development period of Republic's industrial health program, we had carried on most of the work by using personnel of an independent Industrial Health Laboratory of which I was the director. As director of this industrial health service, I trained five chemists of the Research and Development Laboratory of Republic's Cleveland District in the fundamentals of industrial hygiene and field survey work.

Whenever problems requiring special study involving facilities not available within the corporation arise, arrangements are made with the best outside sources obtainable.

Extensive studies, particularly regarding the mining of ore, have been supported. The fine cooperation of the various district engineering, metallurgical, combustion, and industrial relations departments are essential in the functioning of the health and safety program, in evaluating potential health and atmospheric problems.

The cooperation of the chief metallurgist is of extreme importance in helping to evaluate possible health hazards associated with contemplated new processes of manufacture. In this manner, corrective measures are incorporated before the process is put into production.

This active industrial hygiene program has demonstrated its value many times since its inception and is now an integral part of the operations of the Corporation. It is recognized as:

1. A prime factor in protecting the health and safety of all employees.
2. A means of promoting good relations between employees and management.
3. A means of reviewing fraudulent claims involving impairment of health of employees.

Atmospheric Pollution Program

The industrial hygiene service activities were expanded to include atmospheric pollution in 1944.

In 1944, because of the pressure of the war effort and the installation and putting into operation of a new battery of coke ovens, there was considerable controversy because of dust and smoke claimed to arise entirely from one of the Cleveland District operations, and it became necessary to determine the actual facts concerning possible property and health damage from dust, fumes, and gases.

The residential area involved is zoned for manufacturing and while some discussions had been held prior to putting the new coke oven battery into operation during the summer of 1943 there had been no serious allegations. From the middle of July 1944 to February 1, 1945, 1,442 series of air pollutant samples were obtained at 14 stations, seven in or bordering on the complaint area, and seven in other industrial and residential areas of Cleveland.

This air sampling survey was run continuously for 24 hours a day and seven days a week in order to evaluate the influence of weather conditions. These air samples were analyzed for sulfur dioxide, carbon dioxide, phenol, cyanides, dust fall or settled dust, and dust counts.

The following details on results of analyses of these samples were pertinent in determining the damaging effects of these pollutants:

Sulfur Dioxide

During this period, 842 tests were made for sulfur dioxide. The average sulfur dioxide for the whole of Cleveland was .3 part per million of air and that for the complaint area was the same. The highest concentration found was, on one occasion, 1.9 parts per million on the edge of the heavy industry area, not related to a steel plant.

Carbon Dioxide

Since the concentration of carbon dioxide which can be tolerated for constant exposure over an eight-hour day is 50 parts in 10,000, and since carbon dioxide is not poisonous, only seven tests were made. These tests showed an average of .03 percent, or three parts per 10,000, for an overall average of the city and the same for the complaint area.

Carbon Monoxide

One hundred and twenty-seven carbon monoxide determinations were run by the iodine-pentoxide method. The average concentration found in the air in the complaint area was the same as at all other sampling locations around Cleveland averaging nine parts per million of air, an insignificant amount in consideration of a health hazard.

Phenol

Nineteen air samples taken and analyzed for phenol showed results equal to or less than the accuracy of the method of determination. The tests were of value only in demonstrating that phenol, if at all present, was there in insignificant quantities.

Cyanides

Eight determinations for cyanides were negative.

Dust Fall

Seventeen stations, mostly in the vicinity of the complaint area and on the plant property, were established. At these stations, settled dust was collected in water in white enameled pans exposed for known periods of time, usually one month. The results, while relative, showed that only 1/17 of the weight of dust was found in the pans in the complaint area as compared with that caught in the pans on the plant property. This dust showed on analysis a carbon content of 55 percent and a total organic content of 75 percent.

Dust Counts

Due to the fact that complaints had been registered regarding the impairment to health, 859 dust count determinations were made. The dust counts evaluated the number of particles less than 10 microns in size, or, that is, respirable dust. The average dust count for the city was 1.7 million particles per cubic foot of air while that of the complaint area was 1.8.

Vegetation Damage Studies

Dr. Wernham, a plant pathologist from Pennsylvania State College, was employed to make seasonal surveys in not only the complaint area but also throughout the general area of the City of Cleveland. It is interesting to note that his findings did not show any pertinent damage to vegetation directly attributable to any atmospheric pollution.

The presentation of all these data resulted in a verdict in favor of Republic which was later sustained in the Ohio Supreme Court.

Since 1945, the activity of the Air Pollution Sampling Unit has been stepped up and the area of the sampling stations spread out to cover more thoroughly the whole city. The Republic unit has been cooperating with the City of Cleveland Atmospheric Pollution Bureau in running Meteorological and Chemical Surveys periodically in cooperation with and under the direction of the Commissioner.

Five meteorological stations with recorders for wind direction, wind velocity, temperature and humidity have been set up, one of these at a location selected by the City authorities and the others at the four points of the compass surrounding Republic's Plant.

The one station is serviced by the City and records of the others are available to them. The help and guidance of the U. S. Weather Bureau is greatly appreciated by both the City of Cleveland Atmospheric Pollution Bureau and ourselves.

Paint panels are exposed to evaluate paint damage by atmospheric pollution at stations throughout the city and on the plant property. Dust fall studies have been con-

tinued using various types of collectors. At present round stainless steel pots, approximately ten inches in diameter and a foot deep, are used.

These pots are placed in holders so that they are raised twenty-four inches above the surface on which they are placed. In general, a roof on a one-story or higher building is selected for the placement of these dust collectors.

Care is exercised to keep the sampling location away from the shielding influence of walls, chimneys, and trees. Water is kept in the pots to about 1/3 the depth, to entrap the settled dust. In warm weather, the level must be checked frequently to take care of evaporation and excessive rainfall.

In the winter months an anti-freeze is added. The pots are exposed for a month and then replaced with others. Stainless steel lids are put upon the pots containing the collected dust samples, held in place with scotch tape for transportation to the laboratory. The contents are run for total, soluble, and insoluble solids, soluble sulfur and chlorides. Other constituents are at times determined. These results give us data to evaluate the seasonal variation in dust fall, soluble sulfur, and chlorides.

With regard to the soluble sulfur determinations we have found that the concentrations were practically the same during the steel strike periods showing that this is not a pollutant originating in a steel plant. Soluble sulfur deposits were also found in a number of areas far removed from the Cuyahoga Valley. Tests had been run over long periods for oxides of nitrogen and fluorides. Since insignificant concentrations of these substances were found, and there is no evidence of steel plant origin, sampling for them has been discontinued.

Since January 1952, tests have been run periodically at all sampling stations for hydrogen sulfide. These tests were added after a number of complaints of paint discoloration on residences in the industrial area were reported.

The hydrogen sulfide samples are obtained by drawing air at the rate of one liter per minute through a tube containing silver cyanide. The silver cyanide is blackened in proportion to the concentration of hydrogen sulfide in the sampled air. The tubes are sealed and retained for permanent records. The discoloration is evaluated by comparison with standards. This data is correlated with discolorations on paint panels exposed at the sampling stations.

During the past year the following additional facilities were put into operation with a resultant possible increase in atmospheric pollution, which I will comment on in my conclusions:

Operation
#6 Blast Furnace
#7 Coke Oven Battery
#6 Coke Oven Battery
#24 Open Hearth Furnace
#23 Open Hearth Furnace
#22 Open Hearth Furnace
#21 Open Hearth Furnace

Since July 1944, a total of 16,544 samples have been taken in order to evaluate the atmospheric pollution problem.

Dust Counts	3,065
Sulfur Dioxide	4,862
Carbon Monoxide	127
Phenol	19
Cyanide	8
Hydrogen Sulfide	2,089
Chlorides	2,074
Dust Fall	1,000

The following quantitative determinations were made on the dust fall samples:

Soluble Sulfates	1,000
Soluble Chlorides	1,000
Loss on Ignition (carbon)	400

Statistical studies have been made on correlated sampling data to evaluate daily, monthly, seasonal and yearly variations in concentrations of these various atmospheric pollutants. From this volume of data I can draw the following conclusions:

1. The concentrations of sulfur dioxide, hydrogen sulfide, chlorides and suspended dust found are of no hygienic significance.
2. The concentrations of hydrogen sulfide found throughout the City of Cleveland are low.
3. Concentrations of hydrogen sulfide were found in the vicinity of other manufacturing activities as high as those in the vicinity of Republic's plant.
4. A weekday mean of .028 part per million of hydrogen sulfide versus a weekend mean of .025 part per million refutes statements of higher concentrations being emitted over Saturdays and Sundays.
5. The highest concentration of hydrogen sulfide found in the residential areas was 0.16 part per million, with a mean value of .01 part per million. The highest concentration found to date was 2.5 parts per million (one sample only) at a site in the industrial area; not in the vicinity of Republic's Plant.
   Low concentrations of hydrogen sulfide under certain humidity conditions may discolor lead paint. This value is not cited in the literature but the City of Cleveland Air Pollution Bureau claims that .3 parts per million of hydrogen sulfide in the presence of moisture will discolor lead paint. Our findings show that 99 per cent of the concentrations were below .3 part per million. On this basis the odds are at least 1,000 to 1 against damage occurring to lead paint.
   Hydrogen sulfide is less toxic to plant life than other atmospheric pollutants, such as sulfur dioxide, fluorine and hydrogen chloride. Experimental work done at Boyce Thompson Institute for Plant Research, Yonkers 1, N. Y., showed that little or no injury occurred when 29 species of plants were fumigated with less than 40 parts per million of hydrogen sulfide.

6. The averaged concentrations of sulfur dioxide found at the established sampling stations ranged from .06 part per million to .15 part per million. Experimentally, alfalfa (one of the plants very susceptible to sulfur dioxide) grown for 25 days in an atmosphere of .1 to .2 part per million of sulfur dioxide at the Boyce Thompson Institute, compared favorably with a control grown under similar conditions but without the gas.[1]

   These conclusions were confirmed by Dr. Wernham of Pennsylvania State College, our consultant on plant damage from atmospheric pollutants.
7. The frequency of positive hydrogen sulfide tests were greater in other areas of the city than in the complaint area.
8. No positive tests of damage to our exposed test paint panels directly attributable to hydrogen sulfide have been determined to date.
9. The initiation of the expanded steel producing facilities in 1952 has not manifested itself in increased hydrogen sulfide and sulfur dioxide concentrations in the industrial valley area.

Regular Schedule

Meanwhile, air sampling continues on a regular schedule. The stacks, quencher towers, and cooling towers have been sampled and the emissions in particulate matter and gases and fumes evaluated. A panel body truck has been outfitted for atmospheric and plant survey work.

The equipment comprises a gasoline-driven suction pump connected to a manifold, so that eight or more simultaneous air samples may be taken at the rate of from one liter to one cubic foot per minute.

The air samples are drawn in through ports in the roof of the truck so the technicians can work without the inconvenience of inclement weather. There are two auxiliary gasoline motor-driven generators in the truck, together with portable sampling pumps. Folding tables, one for a work table and the other with openings to carry the dust fall pots, are also provided. There is ample room to carry all necessary sampling equipment and supplies to conduct any atmospheric or plant survey in any district of the Corporation.

In order to evaluate the effect of possible damage by these pollutants more accurately continuously over days and months and also to study seasonal effects together with rapidly changing weather conditions, the use of recording instruments is under investigation and development.

Spot sampling indicates existing conditions of atmospheric concentrations only at the time of sampling. While all samples are taken for a minimum of one half hour and many samples have been taken at each sampling station over a period of years, nevertheless intermittent heavy concentrations of short duration may be missed.

[1]P. W. Zimmerman, "Effects on Plants of Impurities Associated with Air Pollution." Proc. of the U. S. Technical Conference on Air Pollution, Pages 127-139 (1952).

Automatic recording samplers also provide permanent records in most instances and eventually we hope to have recorders for all atmospheric pollutants. We are cooperating with the personnel of the City of Cleveland Bureau of Air Pollution Control in standardizing such equipment and have found their guidance and advice of great help.

The Air Pollution Committee of the American Iron and Steel Institute is promoting studies on techniques and methods for the evaluation and control of atmospheric and stream pollution. Their studies and investigations conducted at Mellon Institute and the Industrial Hygiene Foundation have resulted in the development of recorders for atmospheric dust and hydrogen sulfide.

These instruments are commercially available through the Research Appliance Company, Box 413 West View Road, Pittsburgh 9, Pa. Republic helps to support activities of the American Iron and Steel Institute and the Industrial Hygiene Foundation not only financially but with representation on active committees of both associations.

We have five of the dust recorders and one of the hydrogen sulfide recorders set up at several sampling stations under test and observation. After collection of sufficient comparison data, we will attempt to calibrate these samplers.

A continuous hydrogen sulfide sampler employing the standard Greenburg-Smith principle for chemical determination is used in our cooperative monthly sampling periods with the City of Cleveland Air Pollution Bureau. This sampler was developed by one of the members of the Bureau and is now available through the Air Sampling Equipment Company, 4129 West 58 Street, Cleveland 9, Ohio.

The meteorological equipment as previously mentioned comprises wind velocity and direction recorders and hydrothermographs (recorders for temperature and humidity) for each of the five stations. This equipment was obtained from Fries Instrument Division, Bendix Aircraft Corporation, and Instruments Corporation, Belfort Meteorological Observatory, both of Baltimore, Md.

We plan to correlate recorded atmospheric pollution concentrations with recorded weather conditions in order to evaluate the rate, direction and extent of dispersion. Such data will evaluate the basis of any future complaints.

Corrective Measures

During the year 1952, $7,425,000 were expended to directly and indirectly control atmospheric pollution in the Cleveland District alone. Of this expenditure, $265,000 covered fly ash arrestors and dust and fume collectors; $750,000 was spent on incorporating dust and fume control equipment on two new coke oven batteries; $850,000 on electrostatic precipitators on a new blast furnace and additional similar equipment on five existing blast furnaces; $350,000 on improving combustion equipment; five million for three new boilers to replace fourteen small

obsolete ones; and $400,000 in connection with four new 300-ton open hearth furnaces. This permitted additional equipment to be added at the time of installation, to provide oversize flues, increased height of stacks and the most modern type of combustion control to minimize dust in waste gases.

Future Program

The immediate future program calls for a broadening of the entire industrial health and atmospheric pollution programs and correlating all activities. This will promote greater efficiency and flexibility in rendering service to all plants and mines of the Corporation.

Conclusions

In summarizing these comments, while I have given some detailed highlights, you are well aware that it would be utterly impossible to present all the results which we have found so enlightening because of actual facts learned and so helpful in discussing the various problems with our neighbors. Living as we must with other industrial plants of various types, we fully understand both their and our own problems. This is essential in planning new expansion and revamping existing operations.

The actual methods followed in both sampling and analytical work are well grounded on the best known and accepted techniques. We have spared no expense and time in making sure we are scientifically accurate in all phases (physical, chemical, medical, and engineering) of our work. We know our status and are well aware of the situation throughout the areas of the detailed studies.

It has been well shown that Republic has been a good neighbor in the past (and I here explicitly refer to the corrective expenditures made) and while perhaps not "lily pure" neither can they accept the responsibility for all the activity arising from vast operations in the industrial area of a great City. However, it does pay to know the facts.

Air Pollution Control in the Steel Industry

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The melting and heating facilities utilized in the wide range of processes for producing steel products present many and varied problems. And if one considers the size of these facilities and the variety of operations in the steel industry, it is not too difficult to visualize the magnitude and complexity of minimizing air pollution, considering the voluminous quantities of solid, liquid and gaseous fuels consumed.

Most individuals are inclined to think that the steel industry is largely confined to certain and specific geographical sections of the country. However, the mills and furnaces are now spread over 30 states with more than 400 plants making and finishing steel in 250 communities.

In many communities having steelmaking and finishing facilities, there are presently in force, or in preparation, ordinances to control stack emissions from all types of fuel burning devices. With respect to fuel burning equipment such as blast furnace stoves, boilers and other similar devices, we know that by either changing fuels or by installing mechanical firing or fly-ash arresting equipment, stack emissions can be controlled within a reasonable limit. This is evidenced by the progress already made in steel as well as other industries.

The facilities and the conditions inherent to steelmaking are somewhat dissimilar to those encountered in the average fuel-burning equipment. Excessively high temperatures and complex metallurgical reactions contribute to stack emissions which differ not only in composition but also in color and temperature. This constitutes special problems for which solutions are presently unknown, and allowances should be made in smoke control ordinances to permit studies and research to develop economical and practical methods of abating such emissions.

Problem Realized

Fortunately, in Allegheny County, Pennsylvania, the drafters of the ordinance realized this problem and provided that a program be undertaken to determine practical methods of controlling emissions caused by blast furnaces, open hearth furnaces, and Bessemer converters. Reports indicating the status of the research are submitted annually to the Bureau of Smoke Control. The Ordinance also permitted steel companies to participate in a joint program of research on these subjects if they desired. Accordingly, a joint committee to guide this research was established between several large steel producers, which committee comprises personnel representing operating, engineering and research and technology.

Let us consider some specific steelmaking operations and see what progress is being made by this joint committee in their attempts to abate atmospheric emissions.

Open Hearths

One of the most important factors in ascertaining the difficulty to be encountered in solving an air pollution problem is the size of the particles which are to be removed from the stack gas stream. Beside the factor of particle size, the selection of suitable equipment for pollution abatement requires a knowledge of dust loadings, the chemical analysis of the dust and gas, the amount of gas to be treated, and space available for the equipment.

Open hearth furnaces are operated under very high temperature conditions and the steel bath has certain stages of reactions which may or may not react in the same manner as did the similar stage in a previously made "heat," the term applied in open hearth shops. Since this operation involves not only combustion but also exothermic reactions from the materials charged into the furnace, a quantitative and qualitative sampling program was planned to study stack emissions during the melting and refining.

The method adopted for sampling the dust loading was a modified Brady method. This comprises filtering a metered volume of gas through a paper thimble. From the change in weight of the thimble for a given volume of gas, the dust loadings were calculated.

During the course of sampling, it was found that the dust loadings varied appreciably during the course of the heat and a sampling program was developed that would properly represent the conditions. In order to have comparable data, the heat was separated into six stages or periods namely, melt down, hot metal addition, ore boil, lime boil, refining or working, and empty furnace.

Many Samples

A large number of samples were obtained for each period and for a number of heats to determine the average and maximum dust loadings. Most of the sampling was done on oil-fired furnaces. The dust loadings varied widely, ranging from almost zero to as high as two grains per standard cubic foot at peak loads. Evaluations showed that the average dust loading was about 0.43 grains per standard cubic foot. Peak loads occurred during the stages of hot metal addition, ore boil, lime boil and when using oxygen for decarborization.

Having obtained quantitative data on dust loading, studies of the particle sizes contained in the emissions revealed that approximately 50% by weight of the dust collected from an oil-fired open hearth is smaller than 5 microns, with only a few present above 20 microns. Many particles smaller than one micron are contained in these samples. The minute size of these particles can be appreci-

ated when one considers that the smallest individual particle visible to the naked eye is 10 microns; the minute particles in cigarette smoke are about 0.1 to 0.2 microns in size.

To digress for a moment, fume, which is defined as the product of vaporization and subsequent condensation of a material, produces a particle size ranging between 0.1 and 1.0 microns. "Dust" is considered as mechanical dispersoids created by dispersing larger masses into materials as is done by grinding. By the grinding process it is difficult to obtain particles smaller than 5 microns in size. This exceedingly large difference in size between fume and dust particles is most readily contrasted by the fact that a 10 micron dust particle has 8,000 times the volume and weight of a ½ micron fume particle, both having the same composition.

Chemical analysis of the samples obtained showed an iron oxide content of about 90%.

During the process of making steel in an open hearth furnace, the color of the flue gases emitted from the stack varied from white to reddish brown. It was attempted to correlate the dust loadings with the plume color, but compilation of such data revealed a lack of correlation between these two items which precludes utilizing a modified Ringelmann Chart for open hearth stack emissions. It would be a most convenient and less expensive method of sampling if the use of a photoelectric cell could be adapted to indicate the contents of the stack effluent. Attempts to incorporate such an instrument will be tried.

As soon as the study of open-hearth dust loadings at the various open-hearth shops with their different methods of operation was completed, an investigation of equipment to control the emissions was undertaken.

The fact that there is a large percentage of fume present in the stack gases from an oil-fired open-hearth indicates that either an electrostatic precipitator or a high-energy requirement wet washer will be needed to reduce the solid content of the stack emission by more than 50 to 60 per cent.

Electric Precipitators

Electrical precipitators, under the right conditions, will remove particles of any size from the gas. An upper limit of 15 microns is generally adopted because particles above this size are usually removed less expensively by other methods. The advantage of the electric precipitator is that there is, in general, no theoretical limit to the efficiency obtainable. Of course, high efficiency requires large installations and, therefore, high costs. A problem in electrostatic precipitation is that in many cases the particles in the gas stream must be conditioned in order to bring the equipment to a practical operating size. The main effect of conditioning is to impart a high surface conductivity to the particles in order to permit the discharge of ions to the collecting electrode. Water vapor or other conducting substances, which can be absorbed on the particles, are added in those cases where the surface conductivity of the particles is inadequate.

While in most cases lower gas temperatures are desirable, an optimum temperature of about 700°F has been found for the case of cement dust, and a few precipitators are operating at much higher temperatures than this.

Dust Washers

Dust Washers have been widely used by industry and are quite effective in applications in which the particle size of the dust to be removed is not too small. They can be used to remove particles down to 0.1 micron. However, the finer the particulate matter to be removed from the gas by the washer, the greater will be the power requirement per thousand feet of gas cleaned. In practice, this energy is applied in three ways. In some dust washers the energy is supplied by high pressure water sprays. Water pressure as high as 4,000 pounds per square inch has been used. In other cases the energy is supplied by the gas, as in the case of the Venturi scrubber. In this unit the gas passes at very high velocity through a sheet of water. The sheet of water is broken up into extremely fine droplets. In the third type of washer, the so-called disintegrator, energy is applied in mixing the gas and water in the washer itself.

The reason that so much energy must be used in a washer removing the small particles is that these particles have so little mass that it is difficult to bring them into contact with the water. They tend to act like a gas and move away from the water droplets.

There are two additional disadvantages associated with the use of dust washers: first, the high maintenance costs resulting from corrosion; and second, the difficulty in removing the particles from the water in order to comply with stream pollution laws. The latter problem is especially acute when removing particles of very small size.

In addition, in some localities water is in short supply and its price may make its use prohibitive. Where wet washers are used to clean stack gases just before discharge to the atmosphere, a plume of steam is usually seen emerging from the stack. This may be very undesirable, since the appearance of the stack gases may be as bad after cleaning as before. This factor of appearance of the stack gases rather than the degree of cleaning of the stack gases has been emphasized of late by many of the large public utilities. They feel that the public will be convinced that they have ceased to pollute the atmosphere only when the stack gases are nearly invisible.

Many Studies Made

Several types of equipment, such as sonic coagulators, pebble filters, dry and wet type collectors, and electric precipitators, have been studied in connection with open-hearth gas cleaning, but the results have not proved too encouraging. However, the cost of installing and operating

such equipment appears to be very high and may be prohibitive, particularly if the stack must be rendered visually clear, which requires a reduction of 95 to 98 per cent in the stack emission. Further experimentation on a pilot plant basis on an open hearth furnace with an electric precipitator, singly, and in various combinations with dry and wet dust collectors, is scheduled for the near future to accumulate data on efficiencies and costs. The development of less expensive equipment to clean fumes from gas is a challenge to the gas cleaning industry.

It may be well to mention at this time other results which have been obtained on dust loadings from open-hearths. Data of this kind obtained from open-hearths in Los Angeles County, have been published which show loadings averaging 0.8 grain per standard cubic foot. However, because of the nature of the scrap used and the fact that since there is no blast furnace operated in conjunction with the plants, all the metal charge enters the furnaces cold, and the nature of the dust is quite different from that found elsewhere.

Published data on the open-hearth stack loadings at the Donora plant of the American Steel & Wire Division show a dust loading of 0.02 to 0.07 grain per standard cubic foot, using natural gas as a fuel. Some preliminary data, which have been taken in the Pittsburgh district, have shown dust loadings of 0.10 to 0.40 grain per standard cubic foot when natural and coke oven gas are used as fuels.

It has been determined that about 90 per cent by weight of the solids collected from the stack gases of a gas-fired open-hearth are smaller than five microns. This size distribution means a difficult cleaning problem. Because of the small particle size, the stack gases appear dirty, even though the fume is present in small amounts. This then is another case wherein it must be decided whether the standard for cleanliness is to be measured in concentration of solids or is to be a visual inspection of the color of the stack gases.

The recent practice of using oxygen applied directly to the bath during the working period of the heat may add a complication. There is a reference in the literature[1] to the use of a Venturi scrubber for removing the dust under these conditions. It is reported that the mean diameter of the particles is in the range of 0.25 to 0.33 microns with many particles down in the 0.50 to 0.10 micron range. Efficiencies of 97 to 99.7 per cent, on a weight basis, were reported, but the power requirements and maintenance costs are reported to be extraordinarily high.

Bessemer Converter

There does not appear to be a ready answer to this problem. A major difficulty lies in the design of a suitable arrangement to confine the gases for treatment. Once the gases have been confined, the dust loadings and the characteristics of the solids will be measured. There is now being conducted on a small scale an investigation of a method to confine gases and determine the volume and dust content and composition.

The articles contained in this issue of Air Repair represent the balance of those given at the Baltimore Annual Meeting. Authors wishing reprints should file their requests with Headquarters which will advise as to cost for the number of reprints desired.

AISI Research Program

Additional help on these problems can be expected in the future from the work sponsored by American Iron and Steel Institute at the Industrial Hygiene Foundation at the Mellon Institute. They are working for the most part on sampling methods and training personnel for air pollution abatement work in the various steel plants.

Blast Furnaces

The cleaning of blast furnace gas has long been a well established art. It is being practiced on a huge scale. Today, more than 7,000,000 standard cfm are being cleaned.

Since the dust particles in blast furnace gas vary from one-quarter inch to a tenth of a micron, the plants are arranged to remove the dust in three stages. Cyclones remove the large particles, low-energy requirement wet-washers (primary cleaners) remove the next smaller sizes, and electrical precipitators or high-energy requirement wet-washers (secondary cleaners) remove the smallest size particles. Although secondary cleaners are being operated with final dust loadings of less than 0.001 grains per standard cubic foot of blast furnace gas, such cleaning can be justified only in those cases where the gas has special use, such as for underfiring coke ovens or for firing stoves. Well-designed and operated primary cleaners meet the requirements of most anti-smoke ordinances.

Many types and combinations of types of cleaners have been used. The primary wet cleaners include stationary spray towers, revolving spray towers, Feld washers, baffle towers, and spray fans. Primary dry cleaners have included modifications of cyclones, centrifugal machines, filters and electric precipitators.

For secondary cleaning, wet and dry electric precipitators, Theissen disintegrators, high-speed disintegrators and filters have been used.

In the case of the wet cleaners, the dirty water must be conducted to a thickener or settling basin. The treatment of the recovered dust consists of sintering or briquetting to prepare it for return to the blast furnace. One objection to thickeners is the large ground space required.

Slips

Blast furnace slips is another problem confronting the steel industry. Every blast furnace operator is extremely

interested in preventing slips because they result in loss of production and materials and cause variation in quality of the iron. This problem has received study by many blast furnace operators and hope has been expressed that present investigations on further instrumentation of the blast furnace to bleed cleaned gas during all but the heaviest slips may lead to a satisfactory solution of the problem.[2] Several modifications of this system have been proposed. It will take considerable time of service testing to evaluate and prove the merits of the various systems.

As the raw materials going into the blast furnace are improved, the tendency to slip should decrease. Therefore, the large investment being made in sintering and coal preparation plants will be helpful in solving this problem.

Still another problem occurs in the case of furnaces producing ferromanganese. The amount and types of dust from a ferromanganese furnace are different than those from a basic blast furnace. Only about 20 per cent of the dust is larger than 20 microns. From the chemical analysis, it has been found that this fraction of the dust is made up mainly of particles of coke and ore. These apparently have been broken off the burden and blown out of the furnace. They are removed from the gas stream by a conventional dust catcher and briquetted for return to the furnace.

The rest of the dust is a true fume having particles sized between one-tenth and one micron. The average particle size is 0.1 to 0.5 micron. The manganese content varies from 15 to 25%. A rather unusual feature is the alkali content of from 8 to 15%. The alkalies which were present in the manganese ores are concentrated by the process of vaporization and condensation and form a part of the fume. United States Steel personnel have undertaken the development of a process for removing the fume from the ferromanganese blast furnace gas. To determine the practicality of the process and to obtain design information necessary for the large plants required to clean the gas, a pilot plant handling 3,000 standard cubic feet of gas per minute was installed. The operations were encouraging and, as a result of this work, a plant has been designed to clean 135,000 standard cubic feet of ferromanganese blast furnace gas per minute. A complete discussion of the many phases involved would be lengthy and would require the preparation of another paper, which would be concerned mainly with the question of disposal of the removed material.

Self-Policing

The steel industry in Allegheny County, Pennsylvania developed and initiated a voluntary "Self-Policing" program directed at accomplishing the broad objectives of the Allegheny County Smoke Control Ordinance by means not specified in the Ordinance. Each plant has a smoke abatement coordinator to whom are reported infractions together with causes and corrective measures applied. A monthly summary of these infractions, if any, on various facilities presently covered by the Ordinance is compiled by each plant and transmitted to a central point within the individual company. All infractions are tabulated on a final report form which also includes their causes, corrective action, and what present or long range program is contemplated to minimize infractions. This form is then signed by a Company representative and submitted to the County Director of Smoke Control.

This "Self-Policing" program involves considerable time and work, but it serves a definite and useful purpose. First, all operators of combustion facilities are made more cognizant of their responsibilities to perform their duties correctly and efficiently. Secondly, it brings to the attention of the plant officials what operators are dilatory in their approach to smoke abatement, and disciplinary action is applied if previous instructions and warning have been disregarded. Finally, an over-all picture is presented to company officials as to what is being accomplished. They in turn can discuss the different aspects of the smoke control problem with the coordinators and plant officials.

Summary

This paper has discussed the experiences that the steel industry has had in Allegheny County in attempting to solve several air pollution abatement problems of particular concern to the industry. There can be no such thing as push button control in the steel industry because each type of facility represents an individual requirement for study, with particular units of a type presenting even further problems to solve and overcome.

Acknowledgements

The information on open-hearth dust loadings was furnished by Messrs. J. N. Hornak and F. E. Havrilla of the United States Steel Corporation.

[1]Jones, W. P.: Industrial and Engineering Chemistry, 41, 2424 (1949)
[2]Janecek, Frank: Iron & Steel Engineering, 27, 62 (1950)

Air Pollution Control in the Bethlehem Steel Company

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Even though the title of this paper alludes to the entire Bethlehem Steel Company, the discussion for the most part will be devoted to the Sparrows Point plant which is the largest single industry in the Baltimore area. What could be more fitting in a convention meeting of this Association than to outline the air pollution control practiced at the largest industry in the area where the meeting is held.

The Sparrows Point plant is about 12 miles from here on a tract of land located between the Patapsco River and Chesapeake Bay. The land was deeded by Lord Baltimore to Thomas Sparrow in 1652,—hence the name Sparrows Point. About 235 years later the Pennsylvania Steel Company chose this location as the ideal site for a blast furnace and the first pig iron was poured in 1889. The first heat of Bessemer Steel was made two years later. The plant was purchased by Bethlehem Steel Company in 1916.

Characteristic of the expression "mighty oaks from little acorns grow," the Sparrows Point plant has grown steadily from the small beginning about 1890 to become the second largest steel plant in the world—its current annual steelmaking capacity being nearly 6,000,000 tons. To produce this quantity of steel requires about 7,200,000 tons of iron ore, 2,000,000 tons of scrap, 4,500,000 tons of coal, and 2,000,000 tons of limestone. The quantities involved take on greater meaning if we convert them to the amounts of material consumed during the 20-minute period allotted for the presentation of this paper. Hence, by the time this paper has been concluded, 275 tons of iron ore, 75 tons of scrap, 170 tons of coal and 75 tons of limestone will have been used at this plant to produce 230 tons of steel.

The Problem

Before discussing what is done in the way of air pollution control at our nearby plant, let us start at the beginning by reviewing and defining the problem. Steelmaking for the most part is one series of metallurgical operations carried on at high temperatures. Large quantities of solid, liquid and gaseous fuel are burned, and significant amounts of the process ingredients find their way into the air or gas streams which are a necessary part or ingredient of the process. For example, about 8 tons of air enters into the making of one ton of steel. Converted to more meaningful terms, air is used at the rate of about 2.5 million cfm at Sparrows Point. Some of this air becomes, heavily laden with iron and its oxides by the time it has served its primary function in the process, other portions with sulfur compounds, and still others with a multitude of contaminants both gaseous and solid. Air pollution control in steel plants, then, is directed at (1) removing most of the objectionable impurities from the air or gas discharged to the outside and (2) keeping to a minimum the escape of pollutants from other miscellaneous or unpreventable sources.

Coke Ovens

Conventional coke ovens in steel plants release extremely minute amounts of impurities to the air by comparison with the now almost obsolete beehive ovens. The volatile matter (gases, liquids and solids) given off from the coal during the coking process is collected in a piping system and recovered in the by-products plant in the form of tar, benzene, toluene, naphtha, naphthalene, pyridine, ammonium sulfate, and other commercial products. These chemicals or their intermediates were allowed to escape into the atmosphere by the bee-hive coking procedure, but it is now essentially standard practice to recover them. The cleaned coke gas, which is very high in hydrogen and methane, is an excellent fuel and is used in the plant for this purpose or is sold. It is not important as regards air pollution at Sparrows Point although it may be at some steel plants.

Much of the sulfur in the coking coal finds its way into the coke gas in the form of H_2S. When the gas is burned, SO_2 is formed and may create a problem depending upon the geography, meteorology, and nearness of the furnace stacks to houses, sensitive vegetation, and the like. Even though the sulfur dioxide from the coke gas fuel consumed in the nearby plant has not been troublesome air pollution-wise, metallurgical considerations and the need for sulfuric acid make it advisable to desulfurize much of the gas and to manufacture sulfuric acid from the sulfur removed. Consequently, a sulfuric acid plant is now under construction and when it goes into operation the H_2S content of the cleaned gas will be reduced to about 0.7 gr/cu.ft. from an average content of 4.5 gr.

There is, however, one air pollution problem in the usual operation of the coke ovens which has not yet been solved satisfactorily. This is the brown or black smoke which escapes from the ovens while they are being charged. The amount of smoke escaping can be kept small enough by careful operation to be unobjectionable but it cannot be eliminated. This is one of the few air pollution problems in a steel plant for which a satisfactory solution is not yet available. Fortunately, some of the more down-to-earth ordinances take cognizance of this difficulty and

provide accordingly. Badly fitting or improperly sealed oven doors may permit considerable smoke to escape, but this is merely a matter of proper maintenance and operation.

Blast Furnaces

The blast furnaces account for roughly 1/3 of the air entering steel manufacturing processes. As this gas leaves the furnaces it is heavily laden with solid impurities, mostly iron oxide. However, blast furnace gas cleaning is an old and well established art with the result that the gas commonly referred to as raw gas in the steel industry has been through two cleaning operations and has had more than 99% of its dust burden removed. It has long been the practice to clean some of the blast furnace gas even further before using it. This was done by means of wet type collectors commonly called disintegrators. At present much of the gas is given a final cleaning treatment in electric precipitators which remove all but a trace of the solid impurities.

Blast furnace gas is very high in carbon monoxide. Hence the small portion of it which must be bled to the atmosphere is burned to get rid of this gas.

Like with coke ovens, blast furnace operation presents an erratic air pollution problem which is neither preventable nor controllable in the present state of the art. Occasionally the furnace burden will shift irregularly or slip resulting in a violent rush of gas into the piping system. Such slips sometimes develop greater pressure in the furnace and piping system than can be handled safely. To prevent damage, huge valves high on the furnace open to permit the escape of some of the gas until the pressure returns to a safe operating level. This procedure releases clouds of dust-laden gas to the atmosphere. A completely satisfactory solution to this problem is not in sight at present. More careful furnace operation and control supported by improved instrumentation goes a long way toward preventing slips. Improvements in the preparation of certain raw materials also assist in reducing the number of slips. As of today, however, blast furnace slips occur occasionally and pose a problem to the steel industry and to air pollution control officials alike. Some of the more realistic authors of air pollution control ordinances have taken cognizance of this situation and provided for it in the regulations. Both geography and climate are kind to us at Sparrows Point so that the slips which do occur seldom are felt beyond the plant boundary.

Sintering Plant

The fines in blast furnace raw materials are a constant source of operational headaches and present an aggravated gas cleaning problem if not removed from the blast furnace burden before charging. For this reason it is the current practice to screen the fines from the materials charged to the furnaces. These fines, as well as those recovered in gas cleaners and dust collectors at the different metallurgical operations, are rich in iron and would represent a loss of a substantial amount of raw material if it could not be used in the blast furnaces. They can be adapted to blast furnace use by sintering—a process in which the fines are converted to a large-size, very porous product which responds well to blast furnace processing. A sintering plant has been constructed at Sparrows Point and has been placed in operation less than a year ago.

In the sintering process, air at the rate of more than 100,000 cfm per line is drawn across the belt or grate on which the burning or sintering is carried out. Since the raw materials are rich in fines, as a rule, some of this material is entrained by the air stream before it becomes fused or otherwise fixed in the sinter cake. Conventional practice in the past has been to clean this air by means of large diameter cyclone separators. Such procedure fails to capture much of the very fine material. Consequently electric precipitators have been added to gas cleaning equipment in the stacks of our Sparrows Point plant. This will reduce the dust loading in the discharged air from the sinter belts to about 0.01 gr/cu.ft. from 0.5 gr. which is the usual loading if cyclones only are used.

There are other sources of air pollution at a sintering plant—the most important of which probably is the discharge end of the sinter belt. Here the sintered material which is still hot drops from the belt and slides down a chute. This end of the belt of most sintering lines is enclosed and vented to the outside by means of a large-diameter stack in which air flow is created by the heat of the sintered material. At the Sparrows Point plant the dust is removed from this air by means of small diameter cyclones before it is discharged to the outside.

Open Hearths

Open hearth furnaces constitute the major problem still unsolved, for the most part, in the steel-making industry. According to Bishop[1] dust loadings in stack gases from these furnaces may go as high as two grains per standard cubic foot for momentary peaks during certain parts of the cycle. He reports the average concentration for the entire heat to be 0.43 gr. per standard cu.ft. This dust burden is composed almost entirely of metallic oxides—about 90% by weight being iron oxide. It is extremely fine; one report[1] being that about 50% by weight is smaller than 5 microns, and another[2] that the mean particle diameter is 0.5 microns with no particles above 3 microns. Since the weight of any particle of a given substance increases as the cube of the diameter it is apparent that on a number basis an overwhelming proportion of the solid particles in open hearth stack gases are less than one micron in size. To illustrate this point more forcefully, let us assume that the 50% of the material larger than 5 microns[1] is actually all twice that size or 10 microns, and the 50% smaller is half the stated size or 2.5 microns. By number, 98.5% of the particles are 2.5 microns and 1.5% are 10 microns. While this represents a highly artificial condition as to dust distribution, we find the conclusion borne out in practice. In a recent study of stack gases from a metallurgical furnace where the collector in the

stack was selective as to particle size, we found the filtering efficiency by weight was about 49% and by number was about 2%. Obviously, then, to be satisfactory, a collector for open hearth fumes and dust must have a high collecting efficiency against extraordinarily small particles.

In addition to the fineness of the solid pollutants in open hearth stack gases, one other feature adds to the collector design difficulty. This is excessive temperature. Only two types of collectors available today have the dust collecting characteristics required to clean open hearth gases effectively. These are fabric filter collectors commonly called "bag houses" and electric precipitators. The high temperature of the gases precludes the use of fabric filter collectors unless the gas temperature is reduced a great deal by appropriate heat exchangers. This difficulty has loomed so great up to the present as to discourage research in this direction. Specially designed precipitators have been installed in a few open hearth stacks in this country rather recently. Only time will tell whether this is the answer. There is great need both for research into the fundamentals of separating particulate matter from gas streams, and for applied research on modified versions of equipment now available if a feasible solution is to be found to the open hearth problem.

Electric Furnaces

Since we do not have any electric furnaces at Sparrows Point, the air pollution control aspects of such furnaces will not be discussed other than to say that like open hearths they present a difficult problem because of particle size and temperature of the gases.

Bessemer Converters

Only a very small percentage of the steel made in the United States today is produced by the Bessemer process. At Sparrows Point, for example, there are three Bessemer converters which contribute only about 7% of the steel made at this plant. It may be said without fear of contradiction that from the mechanical standpoint air pollution control at Bessemers is the most difficult single problem in the steel industry. Anyone with a sound solution to this problem can endear himself to many by making the answer known.

Power Plants

Power plants burning solid fuel in steel plants have no problems that are different from power plants elsewhere. Many such plants have collectors in the stacks, although some of the older ones do not. Electric precipitators are rare—the more common type of collector found on such stacks is the dynamic precipitator.

Miscellaneous

There are other individual sources of air pollution in a steel plant but individually or in toto they are minor by comparison with those already discussed. The practice as to air pollution control at these sources varies from plant to plant. At Sparrows Point, for example, we have cyclones on some of the coal crushing operations in the coal handling plant; filter fabric collectors on certain foundry operations, and cyclones on others; spray scrubbers on pickling or cleaning tanks; and a dynamic precipitator on the exhaust from the pipe galvanizing operations, to mention but a few.

Air Pollution Investigations

Air pollution investigations including stack sampling are not a "hit or miss" arrangement in the Bethlehem Steel Company. The Combustion or Fuel Department of each plant carries out studies of this nature routinely at the different steel-making plants. New types of collectors are tested under the supervision of the Research Department. This work is supplemented and the overall program for all plants is coordinated by personnel in the Company Industrial Hygiene Department. One chemical engineer with long experience in air pollution matters and one meteorologist devote full time to air pollution investigations and control problems, and the others in this department give of their time as required to air pollution studies. The Company industrial hygiene personnel are kept in close touch with the situation at the Sparrows Point plant through an industrial hygiene engineer at this plant. He serves as the "watch dog" and is our liaison with the local plant in all matters pertaining to air pollution control.

We can hardly deny that the Bethlehem Steel Company or the nearby Sparrows Point plant has problems in air pollution which remain unsolved at this time. These problems are being brought under control one by one as new advances in technology furnish satisfactory solutions and as time, men, material and opportunity permit. Great strides have been made since the war and even greater ones are in prospect for the near future. We who are engaged in this great movement and, even more so, the public generally, should not lose sight of one fundamental and tremendously important fact. The increase in air pollution in this country during recent decades is a by-product of the vast industrial expansion which in turn has given us a standard of living that is the envy of all other countries. This is not an attempt to excuse our shortcomings in this respect, but rather to show that the inconvenience of increased air pollution is not without its compensations. According to published data which came to my attention recently, there were 3300 lbs. of steel per capita in the U.S.A. in 1900, and in 1950 this figure had increased to 14,500 lbs. per capita. This increase brought with it an increase in air pollution, but it also brought refrigerators, automobiles, automatic kitchens, better highways and a multitude of other things.

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[1]Bishop, C. A.: Some Experiments with Air Pollution Abatement in the Steel Industry. Blast Furnace and Steel Plant, December, 1952.

[2]Allen, Glenn L., et al: "Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County, California." Bureau of Mines Information Circular 7627, April, 1952.

The Weirton Air Pollution Program

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National Steel Corporation

Introduction

When an air pollution issue arises between an industry and its neighbors, it is certainly never wise to "let the dust settle before surveying the situation." Nor is it wise to leap on the horse and gallop off in all directions.

We have noted that in typical pollution situations there is usually a grace period between the initial onset and the final storm. This grace period is granted on the basis of the integrity and good faith demonstrated in past situations. It is a wise policy on the part of the company involved to use this period to do some "fact finding" and start corrective action where it is necessary. If the action is prompt and good faith demonstrated, the final storm can be diverted and the bonds of good will strengthened.

When the question of air pollution arose in Weirton, the management of our company assured the people that a positive program would be put into effect. Immediately thereafter, Mr. T. E. Millsop, President of our firm, called a meeting of the top executives and organized a committee to work out a realistic control program suited to the requirements of our town.

To our committee, air pollution control was something new. We were feeling our way along. We talked to various people actively engaged in this field. From these discussions, we found the following generalities that seem to be true.

General

(1) I believe we all recognize that while the cleanliness requirements of a small industrial community are the same as those of a large metropolitan area, the financial burden imposed on the individual to maintain an effective control bureau would be prohibitive.

(2) In addition, I believe that all of you gentlemen realize, and many of you know first hand, how expensive even one installation of moderate size can be. Considering the number of potential sources around a steel mill, it is readily apparent that a *well-engineered* program will be very costly, but a badly conceived program would be financially prohibitive.

(3) Finally, when you put up an expensive house, do you hestitate to put a little more time or money into landscaping to make it more attractive? The answer, of course, *No*. Why, then, as Mr. Edward Pendray pointed out in 1948, spend a lot of time and effort in developing and carrying out a sound technical improvement program and fail to present the facts about what has been done to the people? When you think about it, it seems ridiculous not to expend the effort; and yet, public relations appears to be a neglected cousin in air pollution work.

All of these factors were considered when our program was formulated. The plan we finally settled on consisted of a two-sided approach:

(1) A purely technical program covering:
   a. A community dustfall and gas survey.
   b. A stack emission survey.
   c. Engineering program.

(2) A public relations program covering:
   a. The dispensing of general information.
   b. Information on our program.
   c. Progress reports to the community.

I would like to discuss each of these points briefly.

Technical Program

Community Survey—To obtain dustfall and gas data normally collected and dispersed by a control bureau, we had to establish our own stations. Before we chose locations for our dustfall jars, we compiled a list of the fuels used in the various parts of our plant, had aerial photographs of the plant taken, and secured weather data from the local climatologist. The fuel survey and the aerial photos indicated our major smoke and dust producing areas were those in which the basic steel making equipment—blast furnaces, boiler house, Bessemer, open hearth, and soaking pits—were located.

A statistic treatment of about 1500 measurements of the wind conditions is summarized in Table I.

As you can see, the winds are somewhat vagrant, but, in general, tend to blow from the south and west quadrant. The most frequent velocity encountered was found to be from 4 to 7 miles per hour.

The general topography of the area is typical of the Ohio Valley—a series of rolling hills and valleys with a general slope toward the river. Our plant is located in the main valley near the river.

Accordingly, after we considered all of these factors, we set up 16 stations in concentric circles using the mill as the center of the radii. We attempted to place the greatest number of these jars on the downwind side in order to get the worst conditions. To get around the problems of rooftop placement, we placed our beakers on telephone poles. The height above the ground, in each case, is about 15 feet.

The data indicate that outside of the immediate vicinity of the mill the dustfalls drop off sharply, reaching levels that are comparable to the levels found in similar residential areas in other cities.

Stack Survey—Recognizing that there are limitations of visual judgment on the importance of contributions

from a given source, we have carried out an extensive stack sampling program within the mill area. Our results are in the range found by other people throughout the country. From this survey, we have established the relative contributions from the individual sources. Table II is a summary of our results.

TABLE I

Month	Year	Velocity Calm	1-4	4-10	710
Jan.	1951	0	8.1%	56.5%	35.4%
	1950	0	19.3	51.8	28.9
Feb.	1951	0	10.6	68.0	21.2
	1950	1.7	7.0	52.8	36.8
Mar.	1951	1.6	14.5	37.0	46.6
	1950	0	14.4	51.8	33.8
Apr.	1951	0	1.7	53.0	45.6
	1950	3.3	15.0	57.3	23.3
May	1951	0	16.1	53.3	30.5
	1950	6.9	32.8	39.7	20.7
June	1951	0	18.3	50.0	31.6
	1950	9.4	28.2	41.5	20.5
July	1951	3.5	23.0	46.5	24.8
	1950	9.7	30.5	41.8	17.7
August	1951	1.7	12.1	69.0	17.3
	1950				
Sept.	1951	0	35.2	44.2	21.2
	1950	10.0	26.6	41.7	21.6
Oct.	1951	6.4	32.2	43.6	16.1
	1950	5.2	29.3	43.2	22.4
Nov.	1951				
	1950	1.7	11.7	50.0	36.7
Dec.	1951	1.6	14.4	53.3	30.5
	1950	0	27.3	54.6	17.7
Two Year Average		3.0	19.6	50.0	27.3

	DIRECTION							
Year	N	NE	E	SE	S	SW	W	NW
1950	5.8	6.4	9.1	7.8	17.9	22.8	14.8	15.3
1951	8.2	4.9	7.7	5.6	20.5	23.4	13.1	18.0
Two Year Average	7.0	5.6	8.4	6.6	19.1	23.0	13.8	16.5

TABLE II

Installations		Per cent of Total Emission
Coal & Coke Boilers	A	80.0
	B	1.0
	C	5.0
Open Hearth	D	3.0
	E	6.0
	F	3.0
Bessemer		0.5+
Sintering Plant		2.0
Coke Plant		
Quenching		2.0
Fuel Burning		0.05
Soaking Pits		0.01

TABLE III

Engineering Action

1. Coal Burning Installations A and C
2. Bessemers
3. Open Hearths—D
4. Sintering Plant

These percentages present only half the picture. When the results of the community dustfall are combined with the emission data and other factors such as particle size and density, stack heights and proximity of the living area to the plant are considered, the picture shifts and we get the sequence for engineering action as shown in Table III.

Engineering Program—Based on our survey findings, our engineering Department has begun taking action. With new installations being planned, we are trying to think in terms of prevention. How does this thinking work? Let me illustrate with some examples of action taken at our mill.

We recently put a new blast furnace into production. It was, of course, equipped with the latest dust collecting equipment. In addition, we have installed flaring equipment to burn the gas during emergency bleeds. At the same time that the blast furnace was being planned, we made plans to put in a new steam generating boiler which is designed to use, as a primary fuel, all of the gas produced by the new blast furnace. This boiler is nearing completion now. The gas will be "precipitator clean" and add not more than 0.1 ton/day to the atmosphere. Occasionally, at casting time etc., we may have to fire with pulverized coal. To deal with this possibility, our design department has already made provision in the building layout for the installation of control equipment if it proves necessary.

Another example of this "preventative" thinking is the new coal washer we put into operation. We have been told that this is one of the few washers in the country being used exclusively for strip coal washing. Performance tests indicate that we are reducing the ash content of our coal by 30%. It is undeniable that ash or gunk which does not get into the furnace cannot be blown out of the stack.

On the existing installations, "cure" is the only method that we can follow. And we are doing this. During the course of our survey, when we found a situation that could be corrected by process changes, we made the necessary corrections. For instance, at our boiler house we follow "swing load boiler operation." I am certain that you gentlemen realize that unless the combustion air is carefully controlled, severe smoking could—and did—result. To correct this situation, our Operating Department installed a new system of combustion controls and provided the operators with smoke recorders to help them during the periods of rapid load swings.

To further illustrate our "cure" action, we found that some of the blast furnace gas being burned at the boiler house was being insufficiently cleaned due to lack of precipitator volume. To correct this situation, we have pur-

chased and are installing additional precipitator capacity. Again in terms of "cure," we now know that other control equipment will be necessary at our boiler house and some of the other installations. We *will* put in effective equipment where it is required. We *are* determined to lick this problem technically.

Public Relations—As I stated at the beginning of this talk, in our thinking public relations plays as important a role as engineering accomplishment in this air pollution work:

Engineering experience and economic considerations can tell a company what a reasonable, practical solution to a given problem may be, and even predict within limits the results that can be expected. This knowledge is not readily available to the average layman. So it behooves us as engineers or management officials or municipal officials to translate our specialized knowledge into lay terms and present it to the people. The role of the publication department should be to help us explain the facts. At Weirton we have not adopted a "public be damned" attitude; it is actually a "public be enlightened" policy. We are not surprised to find that the average person when presented with the facts was inclined to be reasonable.

I offer this incident to illustrate my point. In August of 1952, the Weirton City Council asked the company for a meeting to discuss our progress. A committee from our company was selected to meet with the council. A few days prior to the meeting, a member of the local press contacted us to obtain material for an article on smoke control. She visited our plant, was shown the work we were doing on air pollution, and was given all the material that we had on the general problem. The outcome of her visit was that a series of three articles was published covering the general problem and our specific problem and efforts. When we walked into the Council meeting, we did so wondering whether we had done the right thing in being so frank. Subsequent events proved we were right. We found a council that was already informed of the general nature of our work and prepared to ask specific questions that had occurred to them. At the close of the meeting, their expressions of confidence in our program were gratifying. To follow up on this incident, our Publications Department arranged a small spread—a story in pictures of our work during the year—in our company Bulletin. The widespread local distribution this magazine receives practically insured that most of the Weirtonians knew what we were doing.

At Weirton we have further supplemented the policy of informing the public by talks by our pollution engineer before local organizations. These talks discuss the problem in general and present facts about present day limitations in this field. The messages of confidence received from these organizations after these talks seem to indicate that we are "getting thru" to the people.

This is not to say that "you can wrap up a fire in paper." It cannot be done. There has to be a solid basis of fact and accomplishment before public relations can be effective. When used in the right proportions, about nine parts engineering to one part public relations, community and industry relations can be cemented by a strong bond of good will.

Summary

To summarize briefly, we of the Weirton Steel Company, feel that we have worked out a program that fits the needs of Weirton. Our technical program is based on a survey to establish the facts after which our Engineering Department can take appropriate action. Our engineering people are now thinking in terms of prevention in all new installations. All along the line, our Public Relations Department will be keeping the community informed of our progress.

We feel that we have a balanced program that will enable us to proceed in a logical, orderly manner to reduce pollution in Weirton to reasonable levels.

Acknowledgment

It is impossible to acknowledge all of the men and companies whose advice, freely given, helped us in formulating our program. We would, however, like to single out Messrs. W. C. L. Hemeon and H. H. Schrenk for their very helpful advice as we went along.

Air Pollution Prevention at a Modern Zinc Smelter

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Josephtown Smelter represents a modern engineering approach to the ancient problem of the smelting of zinc ores. Unlike the other common metals iron, lead, and copper, whose reduction temperatures are well below their boiling points, zinc metal is unique among the tonnage metals in that its boiling point (907°C) is substantially below the temperature (1100-1200°C) at which the reduction reaction between zinciferrous ore (ZnO) and carbonaceous reduction materials (C) readily takes place.

By reason of this peculiarity, the smelting of zinc has always been considerably more complicated and more costly than the smelting of the other common metals. In addition to this complication, the fact that the primary product of the pyro-metallurgical reduction is a metal vapor imposes special problems in the way of preventing loss of product and consequent pollution of the atmosphere.

The chemistry of zinc smelting is relatively simple. The starting material for most zinc smelters is zinc sulfide concentrate. The first step in the winning of zinc is to oxidize the sulfide concentrate to produce a crude form of zinc oxide, called calcine, and to evolve the sulfur as sulfur dioxide gas.

In the old days, it was customary to waste the SO_2 gas; but modern zinc smelters convert the sulfur dioxide into sulfuric acid. The zinc calcine is agglomerated either by briquetting with coking coal or, more commonly, by sintering, on a traveling grate machine of the Dwight-Lloyd type.

The zinc-containing agglomerates mixed with coke are then subjected to reducing conditions by being exposed in a suitably constructed furnace to a source of high temperature capable of supplying the relatively large amount of endothermic energy required to carry out the reduction reaction. In the horizontal retort process, that is, the classical zinc reduction process, the reduction mixture is charged into banks of cylindrical ceramic retorts.

These retorts are externally heated by coal or gas fire and the evolved zinc vapor is collected in a multiplicity of cone-shaped clay condensers luted to the open end of the retort. It is not uncommon to have six hundred or more retorts in a single furnace. As is well-known by those who have had experience with horizontal retort zinc smelting, and as can readily be imagined by those who have not seen this fascinating operation, the minimization of loss of zinc vapor is a problem requiring the most careful vigilance.

This is especially so when we realize that for every mole of zinc vapor produced there is concomitantly produced a mole of carbon monoxide gas. Since the carbon monoxide is non-condensable, it issues from the cool end of the clay cone condenser and burns.

Since the carbon monoxide gas is necessarily saturated with zinc vapor, a certain small but nevertheless significant loss of zinc vapor inherently occurs in this method of zinc condensation.

It is a tribute to the operators of horizontal retort plants that their losses of zinc vapor are as small as they are when the inherent difficulties and limitations of the condensing method are appreciated. On the other hand, it is well-known among zinc men that a little bit of zinc vapor produces an abundance of zinc oxide smoke grotesquely out of proportion to the actual zinc content.

The unknowing, seeing the white haze commonly discharged from the ventilating louvres of a horizontal retort plant are understandably prone to jump to the conclusion that a great deal of zinc is being lost to the atmosphere in such an operation. Actually, the amount of zinc so lost is quite small.

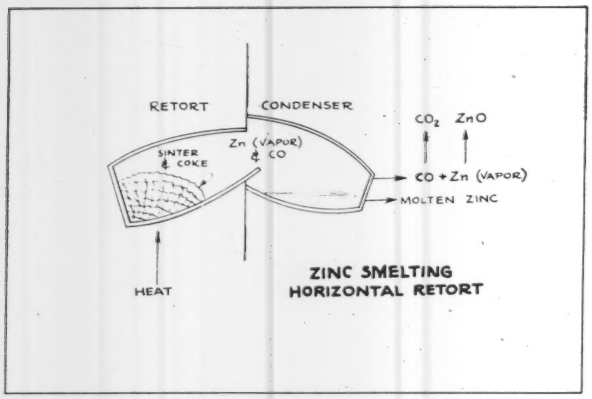
One of the fortunate aspects of a modern zinc smelting process such as the vertical retort process of the New Jersey Zinc Company and the electrothermic process of St. Joseph Lead Company is that the carbon monoxide gas is not allowed to escape and burn, but instead, is cleaned, compressed, and sent back to the plant for use as fuel gas.

Thus, the one major source of zinc loss and zinc smoke has been eliminated by the modern techniques of zinc smelting. By way of illustrating some of the air pollution prevention means utilized in a modern zinc smelter, a brief description will now be given of an electrothermic zinc smelter—the Josephtown Smelter of the St. Joseph Lead Company.

Josephtown Smelter is located on the south bank of the Ohio River in Beaver County, Western Pennsylvania, about three miles southwest of the confluence of the Beaver and Ohio Rivers. The Ohio River valley at this point is approximately a mile wide with hills rising three hundred to four hundred feet on each side.

The trend of the river is southwest. Wind directions are rather random, but tend to be westerly about 70% of the time. The Smelter was built in 1930 and started operations at the end of that year. Construction of Josephtown Smelter marked a historic departure in company policy. Through the first six decades since its organization in 1864, the Company's principal interests were confined to the lead mines of Southeastern Missouri. In 1926, however, the Company acquired a nearly worked out zinc mine (the Edwards Mine) and a prospect in St. Lawrence County in Northern New York State.

By application of modern mining engineering methods,



ZINC SMELTING HORIZONTAL RETORT

the Edwards Mine has been given a new lease on life and to this day is a steady producer. More important, the prospect was developed into the Balmat Mine, one of the major zinc mines of the western hemisphere. When the zinc mines were acquired, consideration was naturally given to the desirability of establishing a zinc smelter.

However, Mr. Clinton H. Crane, then President, now Chairman of the Board of the St. Joseph Lead Company, adopted a basic policy to the effect that the Company would not make a major investment in a smelting process that had shown no major improvement during the past century.

Therefore, instead of proceeding with the construction of a "standard" zinc smelter, the Company began research work (carried out on the premises of the Company's lead smelter at Herculaneum, Missouri) on a new zinc smelting process. An electrothermic process was investigated and felt to have enough promise to warrant pilot plant development.

This research, directed by the late E. C. Gaskill, culminated in the development of a shaft-type electric furnace in which the descending charge of sinter and coke provided a conductor for electric current and, by so doing, developed within itself the endothermic energy required to effect the reduction reaction.

On the recommendation of Mr. Weaton, Mr. Isbell, and Mr. L. T. Sicka (then General Manager, Southeastern Missouri operations) it was decided to construct a commercial plant based on the pilot plant findings. This plant was located in the Pittsburgh area to take advantage of the nearby good markets for zinc metal and zinc oxide and also because this location is not exorbitantly distant from the New York mines.

Another important reason for so locating the plant is that the Pittsburgh area furnishes an excellent market for sulfuric acid. This aspect is important with reference to control and conversion of sulfur dioxide. The good market for sulfuric acid furnishes an economic incentive for minimizing loss of SO_2.

Therefore, the original plant equipment included the latest design of high conversion efficiency acid plant. This is a Leonard-Monsanto contact acid process using vanadium pentoxide catalyst. It was predicted and experience has shown that conversion efficiencies of 95% are readily realized on a consistant basis.

The original plant had an ore roasting capacity of 120 tons zinc sulfide concentrates per day. Present plant throughout is of the order of 600 tons of concentrates per day. The acid plant now consists of three gas purification systems and four contact units. Roasting equipment comprises of five 20′ 6″ diameter 12-deck multiple hearth (Herreshoff) furnaces and two 25′ diameter suspension roasters of the type developed by Consolidated Mining and Smelting Company.

Roaster calcines containing from 1 to 2½% sulfur are agglomerated on the modified Dwight-Lloyd sintering machines of which there are seven, each 44′ long by 60″ wide. Sinter machine exhaust gases are cleaned by rod-curtain cottrells of which a description appears below. Exhaust gases from the acid plant and from the sinter plant are combined in one stack.

For the past 13 years, this has been a 300′ chimney; but with the continued growth of the smelter, positive pressures of over ½″ water at the base of the chimney have required the construction of a new stack which is now being brought into service. The new stack, of reinforced concrete with acid brick liner, is 402′ high and is 18′ in diameter at the top. Concentration of sulfur dioxide in the stack gases is approximately 0.01% by volume.

Sinter and furnace plant dusts and fumes are collected in a 275,000 cfm bag collector which discharges to a 168′ stack. In all there is a capacity of about 1,000,000 cu. ft. per minute of air cleaning equipment in operation at Josephtown.

The agglomeration of roaster calcines by sintering results in the evolution of large quantities of fume rich in zinc, cadmium, and lead. In the early days of zinc smelting, particularly prior to the development of the electrostatic precipitators by Dr. Cottrell, most smelters did not have effective means for removing the sub-micron particles suspended in the vent gases from the sintering machine.

Indeed, it was not uncommon practice for an operator to make corrections in a sintering charge based upon visible operation of the smelter stack. A heavy plume of smoke, reddish-brown in color, was indicative of good sintering operation.

However, the significant losses of metallic values which resulted, coupled with a growing appreciation of air pollution considerations, has made it desirable for present day smelters to install suitable fume collecting equipment.

Large electrostatic precipitators or baghouses are used in this capacity. The electrostatic precipitators at Josephtown comprise probably the largest installation for this application of fume collection in the zinc industry.

Briefly, the sintering operation consists of mixing crushed coke breeze (to the extent of approximately 10% of the weight of calcine) with the roaster calcines and a

percentage of presintered fines, pelletizing with the addition of water, and burning the charge on the continuous grates of the Dwight-Lloyd sintering machines.

The burning coke, assisted by a strong downward blast of air, develops temperatures within the sintering bed in the range of 1400°C. Such conditions of temperature and reduction zones surrounding the burning particles of coke result in the vaporization of approximately 90% of the cadmium, 60% of the lead, and ½% of the zinc contained in the roaster calcines.

As previously indicated the quantity of smoke produced would appear to the untrained observer to be all out of proportion to the actual weights of metals involved. The nominal composition of this fume is 35% zinc, 11% lead, and 7% cadmium.

The collection of sintering fume is not without its problems. One such consideration is the large volume of gas which must be processed. At Josephtown over 1,300,000 cu. ft. STP of sintering machine gases are treated per ton of product zinc produced.

With a capital expenditure for electrostatic precipitators for this type application in the range of two to three dollars per cfm, the cost of collection equipment for a smelter producing 300 tons of zinc per day is appreciable.

Contrariwise with the efficient operation, the value of materials collected affords a satisfactory amortization of this investment. We are fortunate that the values in the fume justify the expense necessary to achieve a high collection efficiency, as contrasted with some industries of having a collected product which is of little or negative value. Thus our joint interests in efficient smelting operation and in prevention of air pollution are served without compromise.

Another consideration in the collection of fume in electrostatic precipitators, one which is most crucial, is that of conditioning the gases to make the fume electrically conductive. Zinc smelter sintering fume is traditionally one of the most difficult to treat effectively by electrical means due to its inherently high electrical resistance.

If the gases are not conditioned prior to the electrostatic precipitator, collection is so seriously impaired that an efficiency of 20% or less results. This compares with an efficiency of 90% and higher if the gases are conditioned sufficiently so that the electrical resistance of the fume is lowered below the critical level. Control of gas temperature and moisture content is one of the most practical means of achieving conditioning in this application.

At Josephtown, conditioning is achieved by treating the gases in chambers prior to the precipitator with large quantities of finely atomized water. These so-called conditioning chambers average 27 ft. in height and 50 ft. in depth with a total volume of 250 cu. ft. per cfm of gas treated. Water at a pressure of approximately 500 psi and a flow of 350 gpm is used to achieve the fine atomization required.

Exit gas temperatures are controlled to a maximum of 130°F with an associated relative humidity of over 70%. Following this conditioning treatment the gases pass to the electrostatic precipitators. Three separate precipitators, operating in parallel, process the 420,000 cfm of gas from the sintering machines.

These precipitators are of the rod-curtain type; shell construction is of concrete with a one inch ceramic lining. Gas flow is horizontal with a rate gas velocity of 4 fps and a total treatment time of 5 seconds. Collection efficiency is of the order of 90% with an associated dust loading in the exit gases of 0.05 grains per cu. ft. STP.

With the construction of the new 402 ft. smelter chimney, two 25 ft. diameter by 50 ft. high concrete cyclone scrubbers were installed to further treat sintering gases before venting to the atmosphere. Gases leaving the electrostatic precipitators enter these scrubbers where numerous sprays discharge approximately 300 gpm of water at 80 lb. pressure.

The limited operating experience with these new units, which have just recently been brought into service, would indicate a collection efficiency of more than 50%, thus the overall removal of fume from the sintering gases is of the order of 95% with a concentration in stack gases of approximately .02 grains per cu. ft. STP.

The handling and processing of concentrates, calcine, sinter, coke, and furnace residue creates great quantities of dust and fume. The control of this dust and fume is important for many reasons—maintenance of safe and suitable working conditions, protection of machinery and equipment, and economical plant operation, as well as the prevention of air pollution inside and outside the plant.

Effective control of dust and fume (other than that from the sinter machines) at Josephtown is accomplished with a central cloth bag collector of 275,000 cu. ft. per minute capacity. Over 100 tons of dust are removed from the 11,000 tons of air which are cleaned every day.

The dust loading entering the collector is about four grains per cu. ft. and the collector operates at better than 99.9% efficiency. The dust has approximately the same composition as sinter and is returned to the sinter circuits. Without the recovery and use of this dust, the overall performance of the smelter would be considerably reduced.

The collector is a 56-section Dracco with 80 eight-inch in diameter by ten-foot long bags for a total of 4480 bags. The sections are arranged in two double rows; a tapered inlet main, 118 inches in diameter at the large end, distributes air to the sections. The discharge duct is 11 feet in diameter and leads to the inlet of a No. 19 SCLD Buffalo exhauster which discharges to a 168 ft. masonry chimney.

The exhauster is powered by one of two synchronous motors which are mounted on a common shaft. A 400 hp, 510 rpm motor operates the exhauster at 225,000 cfm. The larger capacity is used when furnace vapor ring cleanouts are being done; a special duct is provided for this purpose

with an automatic damper actuated through the exhauster switchgear. Division of the dust collector capacity is about as follows:

cfm	
30,000	Furnace preheater draft
75,000	Furnace table smoke rings and residue handling
35,000	Prime Western sinter circuit
50,000	High Grade sinter circuits
35,000	Residue and coke treatment
225,000	Total at low speed operation
50,000	Furnace vapor ring cleanout
275,000	Total at high speed operation

Air distribution through the system is assured by the use of draft controlled automatic dampers.

Individual points of dust and fume generation are hooded or enclosed as completely as possible and exhausted to the collection system. Control is required for bucket elevators; belt, pan, and screw conveyors; trommel screens; crushers; mixers; ball, rod and hammer mills; and furnace preheaters; tables; and vapor rings. Exhaust volumes are adjusted at each point so that control is effected without extravagant use of air.

During the first thirty-five or forty years of this century, it was general practice among the western smelters to waste roaster gases to the atmosphere. In some instances, this practice caused damage to vegetation in the surrounding areas.

Rather exhaustive investigations, notably those conducted by the Agricultural Department of the American Smelting and Refining Company in the Salt Lake Valley and by the Consolidated Mining and Smelting Company of Canada in the Columbia River Valley adjacent to the International Boundary, have elucidated the role played by sulfur dioxide in the growth of plant life.

Although no evidence of any effect due to sulfur dioxide from Josephtown Smelter has ever been discovered in the lands surrounding the plant, the management of Josephtown Smelter felt it worthwhile to develop a body of scientifically accurate knowledge concerning the sulfur dioxide concentration in the atmosphere in Beaver Valley and to ascertain the contribution, if any, that the residual SO_2 emission from the smelter might make.

In 1936 and 1937, the Air Hygiene Foundation of America (now Industrial Hygiene Foundation of America) conducted a thoroughly comprehensive survey of the sulfur dioxide content of the atmospheres of six major industrial cities in the United States, including Pittsburgh. This work was carried out by the use of mobile laboratories developed especially for the purpose.

A description of the mobile laboratory equipment, the mode of conducting surveys, and the results of the surveys are given in Air Hygiene Special Research Series Bulletin No. 1, Parts 1 and 2 (dated respectively September 1, 1937, and January 20, 1938). Each mobile laboratory was equipped with apparatus for taking measured volume samples of air and for determining the sulfur dioxide content by an iodine titration method (modification of the well-known Smith and Friis method) and also for estimating volatile sulfur compounds by the electrical conductivity method of Dr. Moyer D. Thomas.

Air Hygiene was engaged to make an SO_2 survey of the Beaver Valley atmosphere with mobile laboratory equipment similar to that used in the comprehensive surveys referred to above. The first tests were run in the summer of 1938 (June 19-July 29), followed by winter tests during the heating season. Since that time, Air Hygiene has run tests each winter and, from 1941, each summer.

For the initial survey some 36 stations were selected within a five-mile radius of the smelter. Eighteen of the stations were located north of the Ohio River; and 18 south of the river. Three stations outside the five-mile radius were selected to tie in with the aforementioned Pittsburgh survey (Points 201-N, 151-N, and 151-SW in the Pittsburgh region survey.)

During the summer of 1938, 534 tests were made. The average sulfur dioxide content was found to be 0.025 parts per million by volume and the maximum value determined was 0.205 p.p.m. Analyzing the test results with respect to location of the test stations, it was found that stations within a two-mile radius of the smelter averaged 0.0197 p.p.m. SO_2 with a maximum reading of 0.124. Stations without the two-mile radius, but within a five-mile radius of the smelter averaged 0.0385 p.p.m., with a maximum reading of 0.205. Stations outside the five-mile radius averaged 0.0349 p.p.m. with a maximum reading of 0.085.

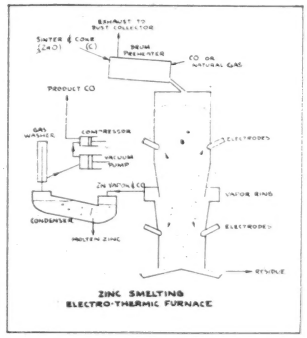
During the winter of 1938-39, 280 tests were conducted. The average SO_2 content of all the stations was 0.05 with the maximum reading 0.66 p.p.m. Within the two-mile radius, the average was 0.04; and the maximum, 0.28. Within the plus two, minus five-mile radius, the average was 0.06; the maximum, 0.28. Outside the five-mile radius, the average was 0.13; the maximum, 0.66.

In the approximately 14 years during which these surveys have been carried out, the constantly recurring pattern is that the SO_2 content found at the stations within the two-mile radius is less than that outside the two-mile radius, Also, the stations on the south side of the Ohio River display a lower SO_2 content than those on the north side.

In all of the tests carried out by Industrial Hygiene, the tests are made on a random time basis, day or night, rain or shine. Incidentally, because of the work being done by an outside agency, none of the smelter personnel knows when atmospheric tests are being conducted.

In 1943, there came into operation a power plant to generate process steam for use in an accompanying government rubber synthetic facility. This plant is located one and one-half miles southwest of Josephtown Smelter.

Since the power plant was scheduled to burn upwards of 1500 tons of 3+% sulfur coal per day, it seemed scientifically interesting to augment the SO_2 surveys to determine what effect, if any, the SO_2 emissions from the power plant have on the atmosphere.



By cooperation with the firm operating the power plant, the survey was extended by adding twenty-three new stations located roughly within a two-mile radius of the power plant. Since the summer of 1943, the augmented survey has been carried out summer and winter. In summing up the long period of observations, neither the smelter nor the power plant seem to make any material contribution to the sulfur dioxide content of the atmosphere.

In general, the surveys show that the highest sulfur dioxide concentrations tend to occur where the population density is greatest, especially in the towns along the Beaver River. Besides domestic and commercial heating, other sources of SO_2 that seem to have occasional influence are brickyards, steel mills, and, before the dieselization program, railroads. Many of the highest SO_2 readings have occurred when railroad locomotive smoke was drifting toward the test car. On another occasion, a very high maximum (1.46 p.p.m.) was traced to nearby incineration.

The thousands of individual SO_2 analyses that have been made are summarized in the following tables.

Table 1 lists the average SO_2 concentrations found in each summer and winter series of tests. Also listed is the maximum SO_2 concentration found in each group.

Table 2 breaks down the above listing into two approximately equal parts: the average and maximum SO_2 values for all stations north of the Ohio River and for all stations south of the Ohio River.

Table 3 arranges the test data with respect to distance between sampling point and smelter or power plant. Three groupings are displayed: the average and maximum SO_2 values for all stations within a distance of two miles of the smelter or power plant; the values for all stations more remote than two miles but less than five miles distant from the smelter or power plant; and finally, the values for all stations further than five miles away from the smelter or power plant.

TABLE 1

	Summer		Winter	
	Avg.	Max.	Avg.	Max.
1938	0.02	0.205		
1939			0.05	0.661
1940			0.03	0.84
1941	0.03	0.178	0.03	0.184
1942	0.02	0.690	0.03	0.185
1943	0.02	0.28	0.05	0.491
1944	0.03	0.34	0.05	0.36
1945	0.02	0.29	0.06	0.73
1946	0.045	0.26	0.02	0.21
1947	0.02	0.21	0.07	0.41
1948	0.02	0.13	0.02	0.20
1949	0.03	0.78	0.06	0.35
1950	0.05	0.43	0.07	0.31
1951	0.024	0.406	0.06	0.31
1952	0.02	1.46	0.06	0.56
1953			0.04	0.37

TABLE 2
SO_2 CONCENTRATION, PPM BY VOLUME
OHIO RIVER

	Summer				Winter			
	North Side		South Side		North Side		South Side	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max
1938	0.032	0.205	0.0177	0.097				
1939					0.054	0.281	0.040	0.239
1940					0.022	0.084	0.016	0.069
1941	0.037	0.178	0.026	0.154	0.025	0.060	0.022	0.054
1942	0.019	0.197	0.027	0.690	0.038	0.171	0.017	0.134
1943	0.03	0.28	0.03	0.26	0.055	0.491	0.049	0.260
1944	0.031	0.34	0.038	0.18	0.042	0.28	0.061	0.36
1945	0.02	0.19	0.02	0.29	0.093	0.73	0.030	0.38
1946	0.05	0.26	0.04	0.15	0.02	0.21	0.01	0.21
1947	0.025	0.21	0.02	0.18	0.09	0.64	0.04	0.32
1948	0.02	0.13	0.02	0.11	0.021	0.13	0.015	0.20
1949	0.03	0.78	0.03	0.19	0.05	0.35	0.06	0.33
1950	0.05	0.14	0.06	0.43	0.08	0.27	0.05	0.31
1951	0.023	0.203	0.026	0.406	0.06	0.31	0.05	0.19
1952	0.01	0.24	0.03	1.46	0.07	0.56	0.05	0.29
1953					0.04	0.16	0.04	0.37

TABLE 3

SO_2 CONCENTRATION, PPM BY VOLUME

	Summer						Winter					
	-2 M.		+2 -5 M.		+5 M.		-2 M.		+2 -5 M.		+5 M.	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
1938	.020	.124	.038	.205	.034	.085						
1939							.042	.281	.059	.280	.125	.661
1940							.018	.069	.024	.084	.029	.035
1941	.028	.154	.038	.178	.041	.077	.021	.053	.030	.062	.017	.030
1942	.018	.197	.023	.350	.052	.690	.016	.097	.042	.185	.037	.085
1943	.03	.26	.04	.28	.06	.17	.042	.410	.058	.491	.088	.283
1944	.028	.16	.034	.22	.093	.34	.048	.150	.040	.130	.120	.360
1945	.020	.29	.02	.19	.06	.17	.016	.730	.094	.520	.143	.450
1946	.040	.15	.05	.26	.05	.15	.010	.210	.020	.090	.070	.210
1947	.02	.07	.03	.21	.06	.18	.040	.280	.10	.41	.16	.64
1948	.02	.08	.02	.11	.05	.13	.014	.20	.025	.13	.03	.11
1949	.03	.19	.04	.78	.06	.13	.040	.22	.04	.23	.11	.35
1950	.05	.17	.05	.13	.10	.43	.06	.25	.09	.31	.11	.25
1951	.022	.406	.029	.203	.025	.071	.05	.14	.08	.17	.13	.31
1952	.02	1.46	.02	.24	.03	.16	.04	.44	.08	.56	.12	.29
1953							.03	.37	.03	.13	.07	.21

Report of The Cleaner Air Week Committee

By Charles N. Howison, *Chairman**

Your CLEANER AIR WEEK Committee has met four times since the Cleveland Convention to plan promotional activities. The committee has done a lot of work during the past year, both in the promotion of CLEANER AIR WEEK last October and in laying plans for CLEANER AIR WEEK in 1953, which was observed during the *week of October 18 to 24.*

While we review briefly the results of the CLEANER AIR WEEK promotion last October, we ask your continued help and cooperation in planning for CLEANER AIR WEEK this fall. The principal purpose of CLEANER AIR WEEK is to focus attention upon the need for control of air pollution from all its sources. The objectives of this event are "a 52-week-per-year job." We urge all members of this association, particularly those affiliated with industry, to request their public relations departments to contribute some time and effort to promoting CLEANER AIR WEEK this year. If each company would draft just one news item, or perhaps an advertisement, or plan some novel display—it would help do a considerable job on a national basis. The CLEANER AIR WEEK activity has been built up to the point where more time is needed to do the kind of job that should be done on a nation-wide basis, than the two or three summer and fall months allotted for this purpose.

*Executive Secretary, Smoke Abatement League of Hamilton County, Cincinnati, Ohio.

Poster Contests

At our suggestion several cities have conducted CLEANER AIR WEEK poster contests as a means of helping the committee select an attractive poster for the national campaign this fall—a poster which will quickly illustrate the purpose and objective of CLEANER AIR WEEK, which is to promote interest in, and action against, various forms of needless air pollution. You have seen some of these posters on display at this annual meeting.

During the past year your committee has received splendid support from public officials, the railroads, industry, magazines and trade publications, professional associations and other groups. Many air pollution control officials have spearheaded the CLEANER AIR WEEK promotion in their communities. Here is what Ralph W. Bourne, Chief Engineer of the Jefferson County Air Pollution Control District at Louisville, has to say about the results of the CLEANER AIR WEEK campaign in his community: "With a little extra effort our CLEANER AIR WEEK program has resulted in:

1. A better informed public
2. Increased public support
3. Active interest of newspapers
4. Better public relations
5. Assistance of civic and public officials
6. Increased prestige for the department

The results are really worth the effort. Any air pollution control official, however small or large his department, is

missing a wide open opportunity if he does not observe CLEANER AIR WEEK in some way."

All-Day Institute

Harry Kunkel, who served as chairman of the CLEANER AIR WEEK Committee in Los Angeles County last fall, sent us several hundred press clippings taken from 22 newspapers in the Los Angeles area having a total circulation of over 2,163,000. The CLEANER AIR WEEK program wound up with an all day institute sponsored by the Chamber of Commerce at the Biltmore Hotel, which was well attended. The CLEANER AIR WEEK project on the west coast was backed by the oil industry, which set up several committees to work on this project.

Many railroads have continued and expanded their activity in the CLEANER AIR WEEK program as a means of promoting fuel conservation and the reduction of air pollution.

In addition to the nearly 30,000 copies of bulletins, news releases, feature stories, proclamations, etc., distributed by your chairman, the committee also received some major support from the Bituminous Coal Institute last fall. BCI devoted a substantial amount of time and effort in the preparation of seven (7) articles and news notes relating to CLEANER AIR WEEK, which were distributed to over 300 newspapers, trade publications and featured radio commentators.

Proclamations Prepared

Governors of most of the states and mayors of a great many cities prepared official proclamations giving CLEANER AIR WEEK official recognition within their jurisdictions. The event received the endorsement of former Secretary of Commerce, Charles Sawyer, who stated that "CLEANER AIR WEEK should serve to strengthen the resolve of the many communities which are now fighting air pollution, and to stimulate action in those communities which have not yet developed their own programs. I am encouraged by the progress which has been made by industry in reducing air pollution by smoke, soot and flyash, although there is still room for progress here and in reducing other air contaminants such as fumes and dusts."

Since the start of the CLEANER AIR WEEK promotion nearly five years ago, we have received scores of inquiries from communities previously unfamiliar with the air purification campaign. We have received communications from civic officials, chambers of Commerce, manufacturers, and individuals in communities from every part of this country and Canada.

We urge your full cooperation in carrying out the purposes of CLEANER AIR WEEK again this year, both as a means of reducing air pollution and to conserve fuels during the current international crisis. We cannot afford to neglect conservation of materials and energy. The United States is wasting millions of dollars worth of fuel through improper equipment and improper firing. When fuel—regardless of whether it is wood, coal, gas, or oil—smokes unnecessarily, that is the sign of extravagance. Thus far science and engineering have not been able to do a whole lot about eliminating pollens and other natural air pollutants, but we know how to do away with smoke and some odors and fumes. It is our intention to bring these facts to the attention of the public during CLEANER AIR WEEK.

We are in the midst of a tremendous industrial expansion—one which promises to continue at an impressive rate into the future. At the same time our traffic and population are steadily growing. Unless the proper precautionary measures are taken, this broad growth can only lead to increasing pollution of the air by smoke, dust, soot and fumes, representing a hazard to health and a grave source of economic waste.

I wish to take this opportunity to thank the Directors of the Air Pollution Control Association who provided the funds ($500.00) for this educational program last year. We have formally requested that $750.00 be allotted by the Board this year, to enable the committee to conduct an effective promotional campaign. I am grateful for the splendid help and cooperation given by the other members of the CLEANER AIR WEEK Committee. The committee greatly appreciates the increased interest and support of the many air pollution control forces that helped make this nation-wide promotion successful.

CLEANER AIR WEEK, October 18 to 24, 1953, should serve to strengthen the resolve of the many communities which are now fighting air pollution and to stimulate interest and action in those communities which have not yet developed their own programs for air pollution control. The Air Pollution Control Association, through this committee, can help all these communities.

What Railroad Managements Are Doing to Control Air Pollution

By G. B. CURTIS
Road Foreman of Engines
Richmond, Fredericksburg & Potomac Railroad
Richmond, Va.

Many years ago railroad management began to realize that the railroads have a responsibility to the public to help keep air pollution to a minimum. However, very little was done about it except that some levels of operating management issued instructions to engine crews and roundhouse forces to cut down on smoke.

Previous to World War I, the cost of fuel for locomotives and power plants was cheap, and the designers of locomotives and power plants were not concerned too much with thought for fuel economy, which in many cases resulted in smaller fireboxes and insufficient heating surfaces in locomotive and powerhouse boilers, and the high-burning rate was reflected in smoke emissions.

Along about the late '20s or early '30s locomotive designers, which in most cases were the railroad mechanical departments, began to realize that the cost of fuel was increasing rapidly and more thought was given to improving combustion on railroad locomotives and power plants. Very little success was realized until the Battelle Memorial Institute, in conjunction with several large railroads, made numerous tests on the overfire air jets as aids to combustion.

Many Tests Made

Railroads in the early part of the century realized that considerable reduction in fuel consumption and a corresponding reduction in smoke emissions could be brought about by the proper amount of air inducted into the combustion area.

At first a row of small holes along the side of the firebox just above the fire line was thought to be of considerable aid. However, the amount of air inducted into the combustion area through these holes in the firebox was limited in its penetration into the burning area and did not create proper turbulence to properly assist in combustion.

Later, steam jets were installed in these tubes or holes to force additional air for combustion and to cause greater turbulence and penetration into the combustion area, but this arrangement was noisy and the crews objected to their use.

Later, a device known as a "Silencer" was developed at Battelle Institute and was demonstrated on two or three railroads, to cut down the noise and at the same time to permit a proper amount of air to be injected into the firebox for combustion and turbulence when the exhaust of the locomotive did not create sufficient draft for combustion.

These overfire steam air jets were of little assistance, however, when the engine was working at sufficient valve travel to furnish enough steam through the exhaust to create the proper draft on the fire. Considerable improvement was also made in the design and structure of the grates in order to get the proper amount of air properly distributed over the entire grate area for proper combustion, or to equalize the distribution of air into the firebox by the aid of baffle plates placed in the ashpan to control the intake of air when the engine was running at high speed, as without the use of the baffle plates in the ashpan or under the grates to distribute the air properly over the grate area, engines running at high speed would get too much air in the back portion of the firebox, causing the fire to burn out quicker in the back of the firebox.

The Diesel

Along in the late '20s or early '30s the Diesel electric locomotive was introduced to the railroads for experimentation. The use of the Diesel electric locomotive was slow in the first few years but by the middle to late '30s it had proved to be more efficient and economical from the standpoint of fuel consumed per unit of power necessary to move tonnage. It was found also that with the advent of the Diesel electric locomotive for both switching and road service, the railroad's worries about air pollution from heavy locomotive smoke was greatly reduced or, in most cases, practically eliminated.

Even before the extensive use of the Diesel electric locomotive for switching and road service most railroad managements were taking seriously their responsibility for the elimination of smoke or the control of air pollution. Smoke committees were formed in most of the large cities where there were as many as two or more railroads entering the city and in most cases their committees were organized well in advance of the smoke ordinances enacted for the control of smoke in such cities.

Railroad managements generally endorsed these plans or instructed their supervisory forces to attend the meetings of these committees and assist in promoting them, and they also sent their supervisory forces to the yearly conventions of the smoke control and air pollution associations.

Speaking for the company by which I am employed, our management equipped all steam locomotives with overfire air induction tubes designed along the lines recommended by Battelle. Most of the large railroads assigned

full time personnel to act as smoke inspectors and to work with the air pollution authorities in the cities.

Old Boilers Eliminated

In recent years many large railroads have eliminated entirely their coal-fired boilers in powerhouses or heating plants and have installed new equipment that practically eliminated the smoke nuisance. For example—a power plant on a connecting railroad almost within sight of my office in Richmond has, within the past few months replaced their coal-burning equipment that had been in use for many years with two 600 H.P. combination gas and oil steam generators, thus eliminating their last remaining smoke complaint in that territory. In some large cities some of the larger terminals have adopted what is known as *Free Steaming*—which is a large powerhouse capacity that will furnish steam to the locomotive boilers before they are fired up, in order that the fire might not have to be built up too rapidly.

It is true that the railroads and all fuel burning plants require constant policing to control air pollution. Every action involving the human factor requires education, understanding and constant supervision to achieve a favorable and workable air pollution program. Since the enactment of smoke control ordinances throughout the nation the railroads have spent huge sums of money on equipment, prepared coal and other auxiliaries in an effort to conform to these ordinances.

Leeway Needed in Certain Cases

The railroads are only one of many factors contributing to air pollution but in a few cases in some sections of this country they have been faced with ordinances that make it almost impossible to comply with.

There are certain recognized conditions where locomotives must have a little more leeway than the usual ordinance permits. For example: when firing up a cold locomotive.

Some large railroads maintain direct steaming enginehouses which permit filling a cold boiler with water and steam to a pressure of 100 lbs. or more. When the fire is lit there are no cold surfaces to interfere with combustion and result in smoke.

The small railroad could not afford to maintain a direct steaming enginehouse as it would prove too expensive, and it has to depend on other means, such as overfire air jets coupled to the roundhouse steam line, portable air jets operated manually by the fire builder, and some depend on low volatile coal.

I might add that low volatile coal is excellent for preparing fires in cold engines and on the ready track as it produces very little or no smoke when handled by experienced firemen, but it is more expensive than high volatile coal and the supply is limited, so that it is not always available.

Close Cooperation

Other means employed by railroad managements to control air pollution called for close cooperation between all concerned in the transportation department. When the roundhouse forces have set the locomotive out in proper condition for the trip the movement director or the yardmaster should not order the locomotive until its train is ready, in order to get the train away as soon as possible.

The train dispatcher is responsible for seeing that the train is not unnecessarily delayed and that no unnecessary stops are to be made for meeting points or for other purposes. Local work should be assigned to as few trains as possible and the roadway department should endeavor to keep slow orders and bottle necks in traffic to a minimum.

The track supervisor should avoid all stops that are not necessary as each time the train is slowed down or stopped the chances for air pollution are increased.

The yardmaster is responsible for receiving the train at the end of its run and he should see that the locomotive it detached from the train as speedily as possible, to be turned over to the enginehouse forces.

It seems to be the opinion of the general public that smoke abatement from the viewpoint of locomotive performance is a matter that concerns the fireman only; that the question of SMOKE or NO SMOKE begins with that member of the engine crew and that he alone is responsible for the observance or the violation of the smoke ordinance. This, of course, if properly considered, is far from fact.

It is a recognized fact that smoke abatement and fuel conservation go hand in hand and that a successful smoke abatement program will show a substantial saving in fuel. Reference has been made already to the type of coal and it is generally agreed that double screened coal can be fired with less smoke and with more efficiency than ordinary run of the mine coal.

Public Attitude

The public attitude toward railroads is reflected in smoke ordinances passed and proposed by most of the major cities in the United States. Some cities have gone so far as to attempt to bar the use of coal-burning locomotives and require the use of Diesel or electric power. The one outstanding criticism of the public in urban areas which has resulted in restrictive legislation is directed at smoke fumes and dirt which originate with the locomotive and roundhouse operations.

City officials have placed the blame on the railroads in public statements for contributions of from 30% to 100% of the total air pollution of cities. Furthermore, it has been found that the general public and municipal smoke officials believe that the railroads are not interested or concerned with this problem.

As railroad men we must convince ourselves that smoke abatement is here to stay and the general public is demanding more and more compliance with the smoke laws. The blame assessed by the public to the railroads must be shared by the management and the operating personnel.

Mechanized Coal Mining and Cleaning and Their Effect on Reduction of Air Pollution

By William Bradbury
Editor, Utilization Magazine

Economics—Incentive for Mechanization

Mechanized coal mining got its start about the year 1923, under economic conditions similar to those that exist today. The trend toward *full* mechanization of the coal industry, as we know it today, began during a post-war period of sustained heavy demand for coal, which prevailed up to the time that depression struck the nation with full force in 1930.

Despite the *high level* of demand that prevailed during the 15 years preceding the depression, coal prices experienced a severe decline in the face of increasingly high labor costs. From a high point of $3.75 per ton in 1920, the average value of coal at the mine source declined still more drastically. By 1932, the average value of coal at the mine had reached a low point of $1.31 per ton, the lowest since 1916. In the meantime, an expanded oil industry was invading coal's traditional markets with devastating effect.

As a result of wartime demands upon the industry, its capacity had become tremendously over-expanded. Meanwhile, there had also been a corresponding over-expansion of the mine labor force. By 1923 there were approximately 705,000 miners on the industry's payroll. This was an all-time high level of employment in the nation's coal mines.

Faced with the situation of high labor costs, declining prices and increasingly severe competition, the industry had to find means of increasing operating efficiency and cutting costs. Getting a higher rate of productivity for the payroll dollar was the only way out. Mechanization of the industry was the answer to the problem.

Production and price levels continued at a low ebb until 1941, when they were once again bolstered by wartime demands. World War II saw a repetition of high demand for coal and production and prices continued firm until 1952, at which time another decline set in. During this second period of increased demand, mechanization made rapid strides and today it might be said that almost all bituminous coal is mined mechanically.

In contrast to the days when mechanized mining was first introduced, productivity has increased from 4.47 tons per manshift in 1923, to more than 7 tons per manshift today. The number of miners required to produce a similar annual volume of coal tonnage has decreased from the 705,000 employed in 1923, to approximately 373,000 today. In the meantime, however, basic daily wage rates have increased from $7.50 to $18.25. The addition of fringe benefits such as the 40 cents per ton contribution to the UMW Welfare Fund, paid vacations, portal to portal pay, and other considerations, have increased labor costs out of all proportion to the increase in productivity.

But for the advancements in mechanization, coal prices today would be out of all reason. Generally speaking, benefits that have accrued from mechanizing the coal industry have been passed along to the miner and to the consumer. The average value of coal at the mine today is $4.88 per ton as compared with $3.02 per ton in 1923, an increase of 61.6 percent. Wages, however, are 143 percent higher than in 1923.

Today, the incentive for mechanization is more pronounced than ever. Diminishing export markets, the rising tide of foreign residual oil imports, and oil and gas competition, have reduced demand for coal to the point where drastic readjustments have become an urgent necessity. Prices of coal in today's market are *by no means* compatible with the costs of production. But coal *must continue* to pay the highest wages of any industry in the country. It's the same old story all over again. High costs, low prices. The industry is meeting today's problem with a further intensification of the mechanization program, thus assuring the consumer of a continued supply of the most economical fuel.

Growth of Mine Mechanization

Mechanical aids to coal mining had been employed long before the mechanization trend got underway. However, these earlier aids to mining merely supplemented the miner's pick and shovel, whereas mechanization as we know it today aims at supplanting manual labor to the fullest extent possible.

The early aids to coal mining consisted of cutting machines and electric haulage locomotives. Cutting machines eliminated the arduous pick work that was involved in breaking down coal from the face. The electric locomotive increased the speed and efficiency of underground transportation by eliminating animal haulage in part. Drilling was done mostly by hand and use of the shovel prevailed 100 percent.

The first step toward mechanized mining was replacement of the miner's shovel by the mechanical loading machine. This was accompanied by improvements in cutting machines to match the capacity of the newly developed loading machines. Electric drills replaced the hand drill and mechanical haulage displaced the mine mule. From that point, progress in mechanization has continued through the years until today practically all of the coal that is produced is mined mechanically. In recent years, means have been developed for completely mechanizing all phases of mining operations. Today, machines that eliminate entirely the need for cutting, drilling and blast-

ing the coal are being used in increasing numbers. These machines, known as continuous miners, perform the whole job of mining and loading in a single operation. It is estimated that continuous mining machines produced approximately 8 million tons in 1952.

About the same time that underground mechanization was getting underway, strip or open pit mining was also being developed. This type of mining is mechanical in every sense of the word. At the present time almost one fourth of bituminous coal production comes from strip mine operations and more than 75 percent of underground production is now mechanically mined. Of the 465 million tons of bituminous coal produced last year, 362 million tons came from underground mines and 103 million tons from strip mines. Of total underground production, 274 million tons were mechanically mined.

Because of the tremendous cost involved, transition to full mechanization of the industry proceeded rather slowly at first. In 1923 only 0.3 percent of underground production was mechanically loaded, although 68.3 percent was mined with the aid of coal cutting machines. Only 2.1 percent of total bituminous production was obtained by strip mining. As of today, approximately 76 percent of underground mined bituminous coal is mechanically loaded and virtually 100 percent is cut by machines. Last year strip mines produced approximately 22 percent of bituminous coal output.

We now come to the question of how mechanized coal mining has affected air pollution. The answer lies principally in the fact that it has resulted in drastic changes in utilization techniques. It has, in effect, taken the shovel out of the boiler room as well as from the coal mine. This is because mechanization has increased the availability of coal of the sizes most suitable for automatic firing. This in itself has made it easier to control the smoke problem, but at the same time has created the added problem of controlling dust and fly ash emission.

In the days before mechanization gained full sway, the emphasis was largely on the production of coarse coal sizes. Practically the only fine coal that was produced was that resulting from mechanically undercutting a thin layer of the coal seam prior to blasting. Fine coal as such was a decided drug on the market.

With the growth of mechanized mining the volume of fine coal production has vastly increased. Fortunately, the development of mechanical stokers and pulverized coal burners has kept pace with the increased production of the finer sizes of coal. At the same time, however, significant changes have occurred in the market pattern for coal. These have had a pronounced effect on the economy of the industry, as well as on the air pollution program. The markets in which coal is presently expanding are those that ignore coal sizes, notably the electric utilities industry. At the same time the markets which formerly absorbed most of the coarse coal production are shrinking. This poses an economic problem for the coal industry inasmuch as its traditional pricing policy of charging more for coarse coal than for fines has been adversely affected by changing markets.

Mechanical Cleaning

Mechanization of mining operations created a need for greater refinement of the raw product. However, since the emphasis at the outset was on lowering the cost of production the matter of upgrading the raw coal product received somewhat less attention at first than could have been desired. The result was, that an erroneous impression was created, one that still persists in the minds of many people, that coal quality in general has deteriorated as mechanization has increased. Contrary to this impression, coal quality by reason of improved mechanical cleaning techniques, is better than ever.

In earlier days, before mechanization, it was the general practice to mine the coal as carefully as possible and ship it to market in much the same condition as it was hoisted from the mine. The miners themselves removed most of the visible impurities from the coal as they loaded it into the mine cars. In fact it was the practice in those days to levy fines against the miner for loading dirty coal. Preparation consisted almost solely of grading the raw coal into a few different sizes and of hand picking slate from the larger domestic sizes of coal. Most industrial and railroad coal was in the form of unprepared run-of-mine or modifications thereof depending upon seasonal market conditions.

Coal in its natural state is usually associated with impurities, most of which can be separated by one means or another. During the mining operation, however, the coal breaks down into a mixture of sizes ranging from fine dust to large lumps plus the natural impurities contained in the coal seam, as well as the occasionally inadvertent inclusion of slate and fireclay from the roof and floor of the seam. Therefore, it is necessary to prepare the raw coal product by sizing, cleaning, drying and in many cases surface treatment, to make a product that is acceptable to the consumer.

The technology of coal cleaning has made rapid strides in recent years and the volume of throughput at preparation plants has increased tremendously. About the time that mine mechanization was initiated, less than 20 million tons a year of mechanically cleaned coal was produced. This was about 4 percent of the total annual coal production. In 1951, an all-time record of 240 million tons of mechanically cleaned coal was produced. This was 45 percent of the entire bituminous coal output. In 1952, total production of cleaned coal was somewhat less volumewise, amounting to 230 million tons. Percentagewise, however, it amounted to 49.4 percent of total bituminous production. It is interesting to note that on the average for every 100 tons of raw coal put through the preparation plant only 83 tons are recovered as clean coal product. This represents another added cost of production.

Mechanized coal cleaning aims at upgrading the raw product by eliminating excess ash and sulfur. Most important, however, is the fact that this factory type processing results in controlled uniformity of quality and size consist, both of which are vitally important in reducing air pollution.

The advantages of utilizing well-prepared coals are sometimes discounted in favor of price considerations. Strangely enough, as the coal producer has sought to improve the quality of his product, consumers and equipment manufacturers have consistently sought to buy and design equipment to utilize cheaper and lower-grade coals. At the same time that the coal industry has invested millions of dollars in preparation facilities the consumer has also invested millions of dollars in equipment to burn poor coal and to overcome the added air pollution problems that obtain with their use. It is reported that one large electric utility company has invested $24 million for the prevention of air pollution. Many others have likewise invested large sums of money for the same reason, principally for the control of fly ash emission. Either there is a definite advantage to preparing clean, properly sized coals, or there is not. It is obvious that the ash that is removed in the cleaning plant can never pollute the air.

This brings us to the question embodied in the title of this paper. What are the effects of mechanized coal mining and cleaning on air pollution? Insofar as mechanized coal mining is concerned it is difficult to say what if any effect it has on reducing air pollution. Suffice it to say it contributes greatly to the national economy by assuring the availability of low-cost fuel supply.

If mechanically mined coal were shipped to the consumer in its raw state the cost of controlling air pollution would be more than prohibitive. Other economic and physical factors would also vastly increase the cost of coal utilization even though the coal could be purchased for less money at the source. In other words, it is more economical for the consumer to have the ash removed at the source than through his ash pits and dust collectors. The price that the consumer pays for clean coal is negligible compared to the cost of producing it.

The question might be asked "to what extent does the use of well-prepared coal save for the consumer some of the costs of installing and maintaining special equipment to reduce air pollution?" The answer is that it can play a considerable part.

Take, for example, the question of fly ash: it is obvious that the greater extent to which coal has been cleaned, the less ash there will be to cause excessive stack emissions. If the coal and the method of burning it do not require the use of electric precipitators, then at one stroke some 75 percent of the cost of dust collecting equipment has been eliminated. It is also obvious that the greater degree to which coal has been cleaned, the less will be the cost of fly ash collection, treatment and disposal.

In the prevention of smoke, as distinguished from dust, coal preparation can play an even greater role. For example, without proper sizing of coal, it is impossible to guarantee uniform rates of combustion on grates. Properly sized coal eliminates segregation on stoker grates, thus ensuring regular primary air flow through fuel beds and proper balance of air in the furnace to prevent cracked hydrocarbons passing up the chimney as soot and smoke. Even in the pulverized coal furnace, improper preparation can cause conditions conducive to smoke. Coal containing too much moisture, by scrambling up the raw coal supply, can put the fuel feed out of balance.

In conclusion it might be said that the contribution of coal preparation to the reduction of air pollution is in proportion to the extent to which it is applied. In general it remains for individual consumers to choose between buying the higher priced upgraded coals or more elaborate and more expensive air cleaning devices. Any way you look at it, clean air is expensive. However, as a representative of the coal industry, I hold to the belief that the best prepared coal is the cheapest in the long run.

Atmospheric Pollution Control in a Chromium Chemicals Plant

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Introduction

In a move to increase capacity and modernize operating facilities at its Baltimore works, Mutual Chemical Company of America decided in 1948 to replace its old plant with a completely new one on an adjacent site. This resulted in creating the largest sodium bichromate manufacturing unit in the world. A prime consideration in the design of this new plant was the determination to utilize the most up-to-date techniques and equipment for purposes of hygiene and air pollution control, to a degree that could not have been accomplished simply by annexing control devices to existing equipment. Much thought and care were given to establishing a work-home in which employees would have a safe and healthful environment. Our present consideration, however, deals only with measures invoked to control general atmospheric contamination.

Just as wet collection of air contaminants can convert air pollution to water pollution, so the clean-up of working environment—the realm of industrial hygiene—by dry collection techniques conceivably could have resulted in more, not less, general air pollution.

To deal with the overall problem, the expert advice of the Industrial Hygiene Foundation of America was solicited. Messrs. T. F. Hatch, W. C. L. Hemeon and their associates at the Foundation were consulted in connection with each major design feature, to be sure that adequate provisions were made to attain the goals desired.

General Description of Manufacturing Operations

In primary chromium chemical manufacture, the operations are chiefly those of producing sodium bichromate. Both metallurgical and chemical processes are involved, and as might be anticipated it is largely the former which necessitates attention to atmospheric pollution control. The chemical operations are predominantly wet processes and accordingly of little significance air pollution-wise.

Basically the metallurgical operation consists of mixing chrome ore with lime and soda ash, and roasting the mixture in inclined oil-fired rotary kilns. For high roasting efficiency, however, the raw materials must be finely ground and intimately mixed. More than a third of the kiln feed is finer than 40 microns in size. Thus storing, conveying, drying, grinding, proportioning, mixing, and roasting more than 900 tons of such material daily could in the aggregate result in excessive dust pollution were it not for proper means of control. Aggravating the pollution potential is the large volume of air and combustion gases that must be handled. The kilns and dryers alone account for several hundred thousand cubic feet per minute. This is worthy of special mention because dust loadings in these gases are far higher than elsewhere; it is estimated that as much as 10% of the total—approaching 100 tons daily—becomes air-dispersed within the equipment and must be eliminated before the exhaust gases finally are emitted to the atmosphere.

Fig. 1. Right: powered ventilators along roof peak. Left center: one short and two tall stacks. Kiln stacks discharging from the electrostatic precipitators. Far left: capped stacks. By-pass stacks used only temporarily in kiln start-ups.

This volume of exhaust gases is dwarfed by the amount of air which needs to be withdrawn from the building to dissipate heat from the dryers and kilns, and maintain a reasonable temperature in the work area. Twenty-four powered ventilator fans in the roof peaks plus other incidental ventilation result in exhausting more than one million cubic feet of air per minute from the main building. To prevent this air from entraining enough dust to cause significant air pollution was a major problem, which could only be solved by making sure the dust would be wholly contained within either operational or collecting equipment.

Air Pollution Control Measures

Mechanical, electrostatic and wet scrubber types of control equipment are utilized. The three illustrations to follow comprise the principal control measures employed. In addition there is incidental use of cyclones, bag filters, and wet centrifugal collectors of conventional styles, used under ordinary circumstances which do not merit detailed discussion. Insofar as possible the units chosen were pilot tested under actual operating conditions in the old

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plant. This was done to test their suitability both from the standpoint of effectiveness in use and to ascertain that they would not introduce aggravated industrial hygiene problems in either operational or repair maintenance.

(*1*) *Raw materials handling*

All of the solids handling equipment is enclosed and maintained under negative pressure to insure against dust leakage, and in its design every opportunity taken to encourage settling of dust within the equipment itself, thus reducing the dust-collecting load.

Screw conveyors, elevators, and bins were made as tight as possible by using welded construction insofar as feasible. Each access opening to conveyors and elevators is outlined with angle frame, against which rests the soft gasket material within a small channel correspondingly outlining the dust-tight cover. The covers, hinged where necessary, are held against the frame of the opening with tee-nuts. The area of each access opening is about 2 sq. ft., and air withdrawal capacity calculated on the basis of a face velocity of 250 ft. per minute.

To allow free passage of air entering the system to the exhaust fan, air passages were designed carefully so that turbulent regions, tending to entrain dust, would be minimized. Thus the vertical walls of screw conveyors extend about three inches higher than the standard casing. No modification of bucket elevators was required, there being ample free cross sectional area for air flow at low velocity. From the conveyor system the air exhaust circuits lead through large bins, where velocity is negligible and dust settling occurs to a greater extent. The suction duct of the dust collector connects to the top of the bin.

Thirteen Hersey-type bag collectors, each of 2000 cfm capacity, are employed. Collected dust is removed from the filtering surface by a continuous back-flow of about 200 cfm compressed air counter-current to the direction of flow of the air being filtered. Dust-laden air enters at the top of the collector and is drawn outwardly by the exhaust fan through cylindrical bags made of piano felt. Bag dimensions are 3 ft. diameter by 7 ft. long.

Dust caught on the inner surface of the bag forms a thin cake. The back blow air is introduced through a pipe ring surrounding the bag. This ring has a discontinuous narrow slot in its inner face. The ring is slightly smaller than the bag in diameter, and is continuously moved up and down slowly over the entire length of the bag. The combination of flexing and continuous compressed air jet through the slot, to which the entire bag surface is subjected several times per minute, serve both to release the collected dust and maintain a comparatively fresh and uniform filter surface. Thus this collector exhibits a constant and uniform pressure drop in the air exhaust circuit. When new bags are installed, the pressure drop increases slowly during the first two to six hours after which it remains essentially constant. The amount of pressure drop depends, in addition to flow rate, on the material being filtered, and is in the range of 2 to 8 inches of water for the substances here involved.

(*2*) *Roasting*

The roasting kilns, also, are operated always under negative pressure, this being made feasible by really effective rotary seals at both ends of the kilns.

Dust-laden gases leave the roasting kilns at about 1200°F and a velocity of 13 ft. per second. Dust removal is accomplished by sequential treatment, first mechanically in settling chambers and second, electrostatically.

Each dust chamber is baffled, dividing it into two sections. Gas velocity in the first section is reduced to about 4 ft. per second, and in the second section to about 3 ft. per second. Inlet and outlet are so arranged that the gases make four 90° turns in passing through the chamber. This combination of velocity reduction and multiple change of flow direction is believed to result in precipitating more than 95% of the particles larger than 40 microns in size.

Six electrostatic precipitators apply the final clean-up to combustion gases from the kilns, and also from rotary dryers. Kiln gases are first passed through waste heat boilers and economizers, reducing the temperature to about 400°F and thus protecting the precipitators from excessive temperatures. One precipitator has a capacity of 40,000 cfm and the remainder 16,500 cfm each.

Auxiliary equipment includes a 480—75,000 volt transformer, having five taps for voltages between 54,500 and 81,800 volts. There is one mechanical rectifier for each precipitator with transfer switches arranged so that two precipitators can operate from one transformer-rectifier system. This affords a spare in case of electrical trouble in either transformer or rectifier. The precipitators usually operate at about 55,000 volts where the output current is 150 to 175 milliamperes.

The precipitators are the plate-and-filament type in which the greater portion of the dust precipitates on the plates. There are 48 perforated plate collectors in four banks of 12 each, in series in the direction of air flow. Between each pair of plates are five filaments or ionizing wires made of No. 10 steel wire. There are more than 200

Fig. 3. Background: three roast quenching stacks, showing steam emission.

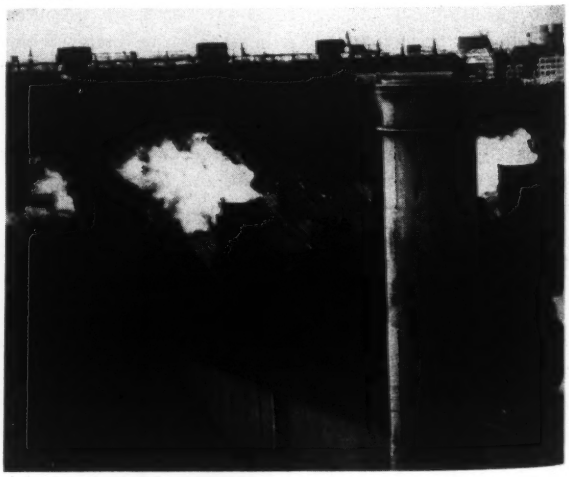

Fig. 4. Left foreground: general air view.

of these wires in each precipitator. The four banks of plates are divided into two sections; the first section of two banks which the gases contact acts as a primary separator, and the last two as a clean-up section. The two sections are vibrated at separate times so that when the primary section is discharging dust, the secondary section catches any which is reentrained.

Gas velocity in the precipitator is about 160 ft. per minute, and the time of passage through the precipitator chamber approximately seven seconds. These precipitators were guaranteed to remove 98% of the incoming dust, regardless of particle size. They exceed this in practical performance, which has proven most satisfactory. The loss from each kiln or dryer stack is only one to two pounds per hour.

(3) Roast quenching

After discharge from the kilns the "roast" is cooled with recovery of sensible heat, but economy prevents cooling it much below 1000°F. Leaching out the chromium in the form of water soluble sodium chromate after roasting is the next processing step. Leaching is a batch operation, carried out with about 65 tons of roast per batch.

The introduction of water to this large mass of hot material—hence the term, "roast quenching"—generates large volumes of steam to be vented to the atmosphere. This is done through stacks 7 ft. in diameter and 65 ft. high. This ventilation effectively prevents the escape of dust-laden vapor inside the building, but initially there was an excessive release of chromium through the stack. Actually the amount emitted was not large—averaging less than 2 lb. of sodium chromate per hour according to impinger sampling—but the bright yellow color of this material gave a yellow cast to the stack effluent and caused yellow coloration of immediately adjacent roof areas.

It was observed that chromate emission was sporadic, inasmuch as yellow color in the effluent appeared in "puffs," and usually more frequent and intense soon after quenching was started. Closer observation indicated that "puffs" occurred when the quenching solution suddenly reached a previously uncontacted portion of the hot roast, e.g., due to collecting in low pockets and overflowing into adjacent pockets.

Originally all of the quenching solution was delivered at one corner of the leaching tank. Early experiments indicated that either a slower rate of delivery or more uniform distribution over the exposed surface of the roast resulted in less chromate being emitted from the stack. Distributing troughs and multiple sprays were tried. Ultimately it was found that a single spray nozzle, centrally located in the stack about 18 ft. above the top surface of the roast, gave the best results. Tests confirm this reduced the chromate emission by about 80 percent, to an average of less than 0.1 lb. per hour. The "puffs" have been eliminated; yellow coloration of the generated steam is rarely seen, and then only in the event of mal-operation. The progress of solving this problem may be followed in the accompanying data tabulation (Table I).

TABLE I
STACK LOSS FROM ROAST QUENCHING

Test No.	Time of Run: hr	Stack Velocity ft/min	Na_2CrO_4 in Gases mg/m^3	Na_2CrO_4 Loss lb/hr
1	7.25	200	25.0	0.71
7	5.93	340	20.0	1.01
8	4.75	310	39.0	1.80
12	2.00	460	20.0	1.30
15	5.75	640	8.6	0.79
24	6.08	555	2.8	0.23
29	7.16	1110	3.0	0.49
33	7.00	250	1.8	0.07
34	6.82	250	3.5	0.11
35	7.03	200	2.5	0.06
36	6.22	200	1.6	0.04
37	6.30	200	2.3	0.06

Appraisal

Because Mutual's Baltimore facilities are situated on the upper harbor waterfront close to other industrial installations and with residential sections nearby, the avowed goal for air pollution control in the new plant was to insure against future nuisance offenses against these neighbors resulting from dust pollution of the surrounding atmosphere. We believe we have fulfilled this objective. The accompanying photographs, taken while the plant was in full operation, are characteristic of the absence of visible plume from stack outlets.

Of interest to those who are confronted with the problem of economic justification of air pollution control is the question of cost. As specific items, the six electrostatic precipitators cost $130,000 plus installation charges, and the thirteen dust collectors cost $60,000, also plus installation. Since considerations of industrial hygiene and atmospheric pollution control influenced the design of the entire plant, it is difficult to segregate their cost entirely; however, it is estimated that the net result of the measures taken for these purposes was an increase of more than 10% in the cost of this multimillion dollar project.

Compensation for Gas Emission Velocity in Calculations of Stack Gas Dispersion

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Synopsis

It is generally recognized that the ground-level concentration of material normally emitted from a stack is reduced if the stack height or stack gas velocity is increased. This is usually considered to mean that stack gas velocity may be substituted for stack height if the circumstances require it. This paper proposes a method of calculation by which the stack-height-equivalent of gas emission velocity may be determined. The theory of the proposed method of calculation is presented in detail, and the solution to a specific problem is given by means of four curves on Figure 6.

It was found expedient in the development of the theory, and in plotting various curves, to utilize a quantity N which is directly proportional to the concentration rather than the concentration itself. The actual concentration of stack emissions in weight per cubic foot may be obtained from the parameter N by multiplying N by the weight of material discharged from the stack in one second and by dividing the result by 3.1416 times the average wind velocity expressed in feet per second.

Explanation of Symbols Used

χ	Concentration in weight per unit volume.
x, y, z	Coordinates, in space, of an arbitrary point.
t	Time
$\frac{d}{dt}, \frac{d}{dx}$	Total derivative with respect to time and with respect to the x-coordinate, respectively.
$\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}$	Partial derivative with respect to the x, y and z coordinates, respectively.
K_x, K_y, K_z	Diffusion coefficients in the x, y and z directions, respectively.
p	A constant proposed by Bosanquet and Pearson partially describing the turbulent state of the atmosphere. Experimental values for this constant range from 0.01 to 0.14 depending on the weather and the condition of the surface of the ground. Smooth surfaces and non-turbulence yield small values for p.
$\bar{u}$	Temporal mean velocity of the wind.
σ	Standard deviation
C	A constant proposed by Sutton partially describing the turbulent state of an isotropic atmosphere. Experimental values for this constant range from 0.243 to 0.081 depending on the gustiness of the wind.
m	A constant proposed by Sutton partially describing the turbulent state of the atmosphere. It lies between 1 and 2 and is related to the diffusing power of the turbulence. An average atmosphere has m = 1.75. Under large lapse rate and large inversions m= 1.8 and 1.5, respectively.
K	A constant proposed by Roberts describing the diffusion process in the atmosphere.
a	A constant of proportionality proposed by Sutton in defining the diffusion and coefficient in the vertical direction in a turbulent atmosphere. It depends on the degree of turbulence and is somewhat similar to p in its behavior.
Q	Strength of a point source emitting matter, expressed in weight per unit time.
Q_1	Volume rate of flow from a stack corrected to 68F and atmospheric pressure.
π	A numerical constant equal to 3.1416.
exp [ ]	The base of the natural logarithms raised to a power equal to the quantity in the brackets.
R	Radius of a sphere or a circle.
C_x, C_y, C_z	Constants proposed by Sutton partially describing the turbulent state of an anisotropic atmosphere. The subscripts refer to the directions in space for which the constant is applicable.
N	A parameter directly proportional to concentration but having the property that its evaluation does not depend on a prior knowledge of wind velocity or source strength.
θ	The angle between the ground and a tangent to the plume centerline at an arbitrary point along the centerline.
Log [ ]	Natural logarithm of the quantity in the brackets.
D	Distance from the ground to an arbitrary point along a constant N-curve.
h	Stack height.

B Height of an arbitrary point on the plume centerline, measured above the top of the stack.

B_{max} Maximum height to which the plume rises, measured above the top of the stack.

α A quantity equal to $\dfrac{2}{Cmx^{\frac{m}{2}-1}} \dfrac{dB}{dx}$

x_o A particular value of x.

v_r Vertical component of stack gas velocity at an arbitrary point in space.

v_1 Vertical component of stack gas velocity at the stack outlet.

s Distance from the stack outlet measured along the plume centerline.

e Base of the natural logarithms, equal to 2.7183.

The design of stacks has always been an important consideration in engineering combustion equipment. Stacks originally provided the draft needed for oxidation of the fuel, and their diameter and height were fixed primarily by this consideration. The present use of forced draft fans to supply combustion air and induced draft fans to purge the furnace combustion products has tended to reduce the importance of the stack for the actual burning process. The primary purpose of a modern stack has become that of providing for the dispersion of combustion products and entrained particulate matter in the atmosphere.

It is generally recognized that the ground-level concentration of material normally emitted from a stack is reduced if the stack height or stack gas velocity is increased. This is usually taken to mean that stack gas velocity may be substituted for stack height if the circumstances require it.

In all cases, a certain amount of substitution of stack gas velocity for stack height must be made regardless of the cost. For instance, some magnitude of velocity is required in order that the combustion products may pass up the stack and be discharged into the atmosphere. In other cases, aeronautical or zoning limitations may prohibit the construction of stacks high enough to produce acceptable dispersion. However, at some point, a choice must be made in every case whether to obtain additional dispersion by increasing stack height or by increasing emission velocity. At such times, a cost analysis must be made to determine which of the two procedures is the more economical.

An accurate cost analysis can be made only after the exact stack height equivalent of gas velocity has been determined. The purpose of this paper is to indicate how such an equivalent may be determined mathematically, using established formulae for atmospheric dispersion and plume rise. The results are presented in the form of a series of curves of equivalent stacks.

Theories of Diffusion in the Lower Atmosphere

In order to determine equivalent stacks, it is necessary to understand how the diffusion of material emitted from a stack takes place in the atmosphere. Until recently, it was thought that the concentration function χ could be determined only by solving the partial differential equation of Taylor (1) and Schmidt (2)

$$\frac{d\chi}{dt} = \frac{\partial}{\partial x}\left(K_x \frac{\partial \chi}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial \chi}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial \chi}{\partial z}\right) \qquad (1)$$

subject to the appropriate boundary and initial conditions. The quantities K_x, K_y, and K_z represent diffusion coefficients in the x, y and z directions, respectively. Their functional form must be known before Equation (1) can be solved.

Roberts (3), Bosanquet and Pearson (4), and Calder (5) solved Equation (1) for the special cases of line and point sources. The mathematics required for solving partial differential equations of the form of Equation (1) is difficult to carry out, and certain simplifying assumptions were required by each investigator. Only Roberts was able to obtain mathematically exact solutions for both infinite line and point sources; however, his simplifying assumption of a virtual diffusivity K was not substantiated when his solution was compared with experimental data. Bosanquet and Pearson derived an expression for K_z of the form

$$K_z = p\bar{u}z \qquad (2)$$

by using certain fundamentals of turbulent flow proposed by Taylor (6). More recently, Calder obtained a similar equation using several well established formulae of aerodynamics. Both Bosanquet and Calder obtained mathematically exact solutions to Equation (1) for infinite line sources; however, each was required to make semi-empirical assumptions concerning K_y and the mathematical form of the final solution when considering point sources. In general, the solutions of Bosanquet and of Calder are in good agreement with experimental data for some atmospheric conditions.

Sutton (7) reasoned that the complex problem of diffusion in the lower atmosphere could best be solved by using an entirely new approach based on the statistical theories of turbulent motion proposed by Taylor. By assuming a relatively simple functional form for Taylor's correlation coefficient, Sutton was able to show that the standard deviation for the scatter of particles from their mean position in turbulent flow was of the form

$$\sigma = \frac{1}{\sqrt{2}} C(\bar{u}t)^{\frac{m}{2}} \qquad (3)$$

where C and m depend only on the degree of turbulence of the flow.

By making use of the definition of σ, Equation (3) may be shown to include the exact solutions of Roberts, Bos-

anquet, and Calder. In the case of Roberts' solution, it is found that $m = 1$ and $C = \sqrt{\frac{4K}{\bar{u}}}$. The exact solutions of Bosanquet and Calder require that $m = 2$ and $C = 2p$. Sutton was able to show in the development of his theory that the above values of m represent lower and upper limits, respectively for this quantity. He indicated that reasonably good correlation between theory and experiment could be obtained in atmospheric dispersion by using $m = 1.75$.

In later publications, Sutton (8) (9) (10) refined his theoretical treatment by modifying slightly the assumed form for Taylor's correlation coefficient. In these later publications, Sutton derived the explicit form of K_z as

$$K_z = a\bar{u}^{-1+m} z^{\frac{2(m-1)}{m}} \qquad (4)$$

which can be seen to be of the same general form as that of Equation (2). The more accurate solutions of Sutton are found to be in excellent agreement with experimental data, however, the formulae are too complicated to use in any but the most exacting engineering calculations.

Sutton's equation for the concentration due to an instantaneous point source of strength Q, located at $x = y = z = O$ in an isotropic medium having a mean velocity $\bar{u}$ is

$$\chi = \frac{Q}{\pi^{3/2} C^3 (\bar{u}t)^{\frac{3m}{2}}} \exp\left[-\frac{R^2}{C^2(\bar{u}t)^m}\right] \qquad (5)$$

when $\bar{u}$ is directed along the positive x-axis. This may be compared with

$$\chi = \frac{Q}{\pi^{3/2}(4K)^{3/2}t^{3/2}} \exp\left[-\frac{R^2}{(4K)t}\right] \qquad (6)$$

which is the corresponding expression for an instantaneous source in ordinary diffusion. In both equations (5) and (6), $R^2 = x^2 + y^2 + z^2$.

By utilizing the mathematical procedures employed with considerable success in heat transfer by conduction (11), Sutton was able to obtain

$$\chi = \frac{Q}{\pi C^2 \bar{u} x^m} \exp\left[-\frac{y^2+z^2}{C^2 x^m}\right] \qquad (7)$$

as the expression for a continuous point source. Here, as in Equation (5), the source is considered to be located at $x = y = z = O$ in an isotropic atmosphere. The mean velocity of the wind is again assumed to be $\bar{u}$ in the direction of the positive x-axis. The mathematics necessary to obtain Equation (7) from Equation (5) is found to be considerably more involved than for the corresponding case of conduction heat transfer.

Equation (5) was generalized by Sutton to include the case of an anisotropic atmosphere by using the following expression for an instantaneous source:

$$\chi = \frac{Q}{\pi^{3/2} C_x C_y C_z (\bar{u}t)^{\frac{3m}{2}}} \exp\left[-\left(\frac{x^2}{C_x^2} + \frac{y^2}{C_x^2} + \frac{z^2}{C_x^2}\right)\frac{1}{(ut)^m}\right] \qquad (8)$$

where C_x, C_y and C_z are the values of C in Equation (3) in the x, y and z directions respectively. It is obvious that when $C_x = C_y = C_z = C$, Equation (8) reduces to the isotropic case. The expression for a continuous point source in an anisotropic atmosphere becomes

$$\chi = \frac{Q}{\pi C_y C_z \bar{u} x^m} \exp\left[-\left(\frac{y^2}{C_y^2} + \frac{z^2}{C_y^2}\right)\frac{1}{x^m}\right] \qquad (9)$$

instead of that given by Equation (7). Tabulated values of C_y and C_z in Reference (10) indicate that at heights greater than 80 feet an isotropic atmosphere may be assumed.

Diffusion Theory Applied to A Simple Stack Problem

In carrying out the present study, several mathematical properties of Equation (7) were found to be of primary importance. These particular properties will be discussed in some detail in the following in order that the reader may become better acquainted with them and thereby understand the basis for certain mathematical procedures used in the next section.

According to Equation (7), either positive or negative values of y act to reduce the magnitude of χ. Since maximum possible concentrations must be considered when designing a stack, the usual procedure is to consider $y = 0$. This, of course, corresponds to investigating the function χ in the x-z plane. For concentrations in the x-z plane, Equation (7) may be written in the form

$$N = \frac{1}{C^2 x^m} \exp\left[-\frac{z^2}{C^2 x^m}\right] \qquad (10)$$

where

$$N = \frac{\chi \bar{u} \pi}{Q} \qquad (11)$$

Fig. 1 is a plot of Equation (10) containing N as a parameter. For this particular case, m and C were taken equal to 1.75 and 0.1709 respectively. Working with the concentration function in the implicit form of Equation (10) has the advantage that N is independent of wind velocity, $\bar{u}$, and source strength, Q. The concentration χ may be determined by multiplying $\frac{Q}{\bar{u}\pi}$ by N.

The horizontal centerline of the plume lies along the x-axis, which is to be expected, since the source is assumed to be at $x = y = z = O$ and no forces exist to cause a rise or fall of the plume as it extends downwind. If the point source is taken to represent the outlet of a stack, it will be located a distance h above the ground. On Fig. 1, the ground must then occupy a position at $y = -h$. A level ground line is shown on Fig. 1 at a vertical distance below the source of 300 feet.

Since an N curve can always be found which is tangent to the ground line, Fig. 1 may be considered to indicate graphically that the N values occurring at the ground at-

tain a maximum value, N_{max}, at this point of tangency. The location of N_{max}, measured along the x-axis, or from the base of the stack, as well as the magnitude of N_{max}, can readily be determined from Equation (10) by use of the differential calculus.

CONSTANT N-CURVES FROM A POINT SOURCE IN A TURBULENT MEDIUM

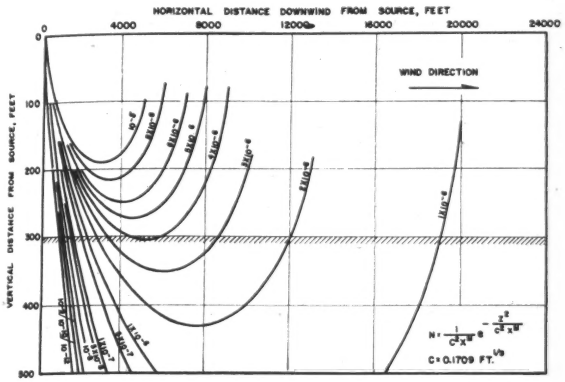


FIGURE 1

At this point, a question arises as to the exact meaning of the magnitude of N_{max} obtained in the above manner from Fig. 1. Strictly speaking, the N curves of Fig. 1 occur as shown only when the atmosphere extends infinitely far in all directions from the point source. If a ground line is drawn at a finite distance below the source, the extension of the curves below this line is of academic interest only. The concentration function in the ground is probably zero, but in any case, it is of an entirely different character from that shown on Fig. 1.

In general, it is necessary to make certain additional assumptions concerning the character of the ground surface. If this surface is such that any material emitted from the stack which comes in contact with the ground is completely absorbed, the concentrations at the ground line, indicated implicitly by the N values of Fig. 1, are true values. However, if no absorption occurs at the ground, that is the ground acts as a perfect reflector of the material being emitted from the stack, the true ground-level concentrations are to be taken as twice as great as those indicated by Fig 1.

In any particular problem, there is a simple calculable relationship between the N values obtained from Fig. 1 and the true concentrations. Fig. 2 indicates the manner in which N_{max} varies with stack height and Fig. 3 indicates the variation of N with distance downwind from the stack and stack height. The ground surface has been assumed to absorb all material coming in contact with it in both Fig. 2 and Fig. 3.

Consider now the case of a plume whose centerline coordinates obey some known mathematical law. Such a plume may rise due to differences in density between the plume and the atmosphere or to a vertical velocity com-

VARIATION OF N_{max} WITH STACK HEIGHT

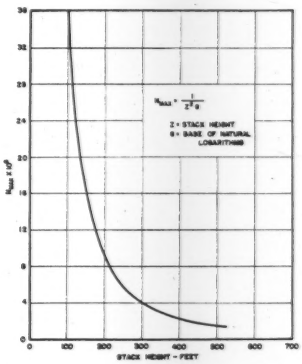


FIGURE 2

ponent at the source. If the plume leaves a stack vertically at some particular velocity, its relative motion with respect to the atmosphere is such as to create an effective wind, directed vertically downward, but not necessarily constant at all elevations. Sutton's equations are not properly applicable to such conditions; however, if it is permissible to assume that only the dispersion resulting from horizontal travel is significant, Sutton's equations may be used even in cases of rising plumes. In the latter cases, the concentration at the point (x,y) which lies on the centerline of a rising plume is the same as that at the point (x,O) for a non-rising plume. Furthermore, the changes in concentration as one moves vertically away from the centerline of a rising plume are the same as those obtained by moving vertically from the centerline of a non-rising plume.

VARIATION OF N-CURVES WITH DISTANCE DOWNWIND FROM SOURCE AND STACK HEIGHT

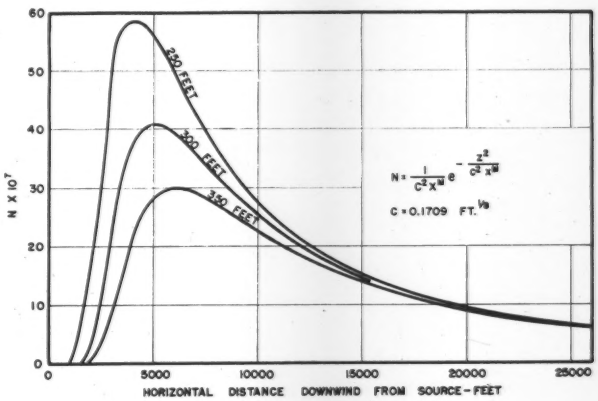


FIGURE 3

Fig. 4 is a plot similar to Fig. 1 for a centerline inclined at an angle θ to the horizontal. Here, as in Fig. 1, it is seen that N attains a maximum at some point along the ground

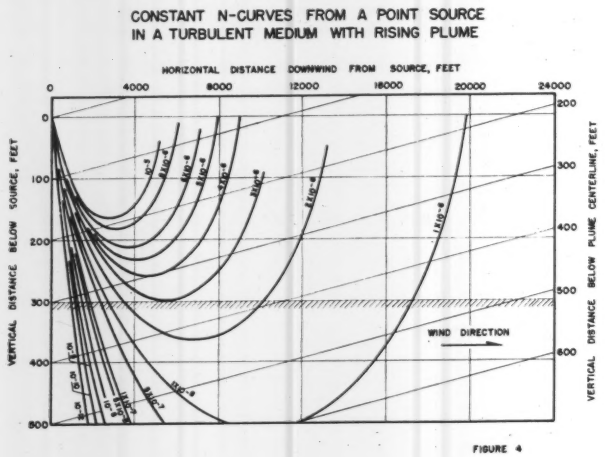


FIGURE 4

line, however it should be noted that the point at which the maximum occurs and the concentration at the maximum point are different from that shown on Fig. 1. The difference is, of course, due to the inclination of the plume centerline.

Further consideration of Fig. 4 and Fig. 1 will show that not only is the location and magnitude of N_{max} changed when the plume centerline is displaced vertically, but the shape of the N curve downwind from the source is also altered slightly. In general, the value of N first increases and then decreases more rapidly with distance when the plume centerline is inclined upward as compared to a horizontal centerline position. This necessitates a precise statement of what is to be implied by the term equivalent stacks. For the purpose of this paper, equivalent will be considered to be stacks which produce the same maximum ground level concentrations. That is, two stacks will be considered to be equivalent when N_{max} is the same for each. This definition does not, of course, imply that N_{max} occurs at the same distance from the base of the two stacks. In fact, the position along the ground at which N_{max} occurs will be different for each equivalent stack.

Analytical Solution for the General Stack Problem

An analytical solution to the problem of equivalent stacks with a rising plume may be obtained according to the following. Referring to Fig. 5, let R equal the distance from the centerline of the plume to the N concentration line. Then, according to Equation (7)

$$R = \left[C^2 x^m \ \text{Log} \ \frac{1}{NC^2x^m} \right]^{1/2} \qquad (12)$$

Also, let B equal the vertical distance from the top of the

SIGNIFICANT FACTORS REQUIRED FOR ANALYTICAL SOLUTION

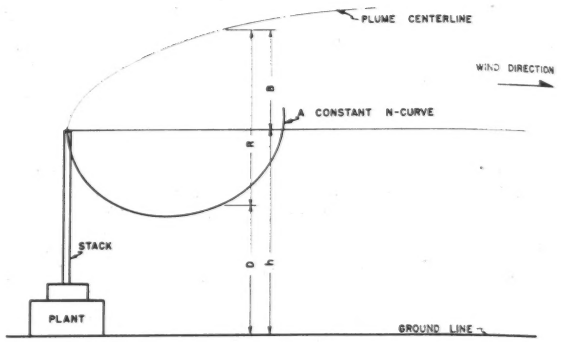


FIGURE 5

stack to the centerline of the plume and h equal the distance from the ground to the top of the stack. Then

$$D = h + B - R \qquad (13)$$

is the distance from the ground to the N concentration line. The quantity $\frac{dD}{dx}$ defines the slope of the tangent to the N concentration line as one moves downwind from the stack. But

$$\frac{dD}{dx} = \frac{dh}{dx} + \frac{dB}{dx} - \frac{dR}{dx} \qquad (14)$$

and since $\frac{dh}{dx} = 0$, this becomes

$$\frac{dD}{dx} = \frac{dB}{dx} - \frac{dR}{dx}$$

Regardless of the functional form of the centerline curve

$$\frac{dR}{dx} = \frac{Cm}{2} x^{\frac{m}{2}-1} \frac{\left[\text{Log} \ \frac{1}{NC^2x^m} \right] - 1}{\left[\text{Log} \ \frac{1}{NC^2x^m} \right]^{1/2}} \qquad (15)$$

therefore

$$\frac{dD}{dx} = \frac{dB}{dx} - \frac{Cm}{2} x^{\frac{m}{2}-1} \frac{\left[\text{Log} \ \frac{1}{NC^2x^m} \right] - 1}{\left[\text{Log} \ \frac{1}{NC^2x^m} \right]^{1/2}} \qquad (16)$$

When D is a minimum, $\frac{dD}{dx} = 0$ and from Equation (16)

$$\left[\text{Log} \ \frac{1}{NC^2x^m} \right] - \frac{2}{Cmx^{\frac{m}{2}-1}} \frac{dB}{dx} \left[\text{Log} \ \frac{1}{NC^2x^m} \right]^{1/2} - 1 = 0 \qquad (17)$$

Equation (17) is quadratic in $\left[\text{Log} \ \frac{1}{NC^2x^m} \right]^{1/2}$ and may be solved for this quantity. Squaring the solution gives

$$\left[\text{Log}\frac{1}{NC^2x^m}\right] = 1 + \frac{\alpha^2}{2} \pm \frac{\alpha}{2}\sqrt{\alpha^2+4} \qquad (18)$$

where $\alpha = \dfrac{2}{Cmx^{\frac{m}{2}-1}} \dfrac{dB}{dx}$.

Equation (18) may be solved for — Log N with the result

$$-\text{Log N} = 1 + \tfrac{1}{2}\left[\frac{2}{Cmx^{\frac{m}{2}-1}}\right]^2\left[\frac{dB}{dx}\right]^2 + \text{Log } C^2x^m \pm \tfrac{1}{2}\left[\frac{2}{Cmx^{\frac{m}{2}-1}}\right]\frac{dB}{dx}\sqrt{\left[\frac{2}{Cmx^{\frac{m}{2}-1}}\right]^2\left[\frac{dB}{dx}\right]^2+4} \qquad (19)$$

By use of Equation (19), the particular N curve which has a horizontal tangent at the point $x = x_0$ can be determined provided $\dfrac{dB}{dx}$ is known. Two such tangents are known to exist, one above the centerline and one below, corresponding to the use of the minus and plus sign before the fourth term of equation (19). Since the tangent lying below the centerline is the only one of importance for stack calculation, the plus sign should be used.

Only one of the infinity of N curves obtained from equation (19) is tangent to the ground line. In order to obtain that one curve, use must be made of the relation that D is equal to zero whenever an N curve touches or crosses the ground line. Thus

$$\left[C^2x^m \quad \text{Log}\frac{1}{NC^2x^m}\right]^{\frac{1}{2}} = h + B \qquad (20)$$

or equivalently

$$-\text{Log N} = \frac{(h+B)^2}{C^2x^m} + \text{Log } C^2x^m \qquad (21)$$

The particular value of x which satisfies Equations (21) and (19) simultaneously locates the point of maximum ground level concentration. The value of N obtained from either Equation (21) or (19) permits the determination of this maximum ground level concentration.

In general, the easiest way to obtain the x value which determines the maximum ground level concentration is by graphical solution of Equations (21) and (19). Of course, B must be known before Log N can be calculated from Equation (21) just as $\dfrac{dB}{dx}$ must be known before Log N can be calculated from Equation (19).

Equations for Plume Centerline

Only a meager amount of information is available for determining the centerline equation of a plume. Sutton (12) considered the case of a heated jet and indicated that one might assume a vertical velocity component which decayed according to the equation

$$v_v = v_1 s^{-1/3} \qquad (22)$$

while the horizontal component was always equal to the wind velocity. The quantity s is distance measured along the centerline, but it may be approximated by using horizontal distance, x, instead. The quantity v_1 may be considered to be an initial velocity whose magnitude is dependent upon the total heat in the stack gas, its specific heat, absolute temperature and density.

When the stack gas temperature is the same as the atmosphere, only the stack gas velocity can cause a plume rise. If it is assumed that the vertical velocity decays according to a power law of the type proposed by Sutton, the available data indicates an exponent of the order of -2/3, and v_1 must be set equal to the stack gas outlet velocity. However, when this is done, the calculated centerline curve is found to differ in some respects from observed cases of plume rise.

In practice, the plume rises almost vertically above the stack for a certain distance which depends to some extent on the ratio of wind and gas velocities. After this almost vertical rise, the plume bends rapidly toward the horizon and after a time becomes practically horizontal. It is this behavior which has led to the use of "effective stack height" instead of actual height when calculating ground concentrations. The calculated curve for the plume centerline, using a power law variation of vertical velocity similar to Equation (22), does not display these particular characteristics to any considerable extent.

Bosanquet, Carey and Halton (13) published equations for the centerline of a plume when velocity, density and a combination of the two resulted in vertical displacement of the plume. Their equations have been presented graphically more recently by Steinbock (14).

Bosanquet's equation for the plume centerline when outlet velocity is the only factor producing a vertical displacement is given as

$$B = B_{max}\left(1 - 0.8\,\frac{B_{max}}{x}\right) \qquad (23)$$

whenever $x > 2B_{max}$. Values of B_{max} are obtainable from an additional equation

$$B_{max} = \left(\frac{4.77}{1 + 0.43\,\frac{v_1}{\bar{u}}}\right)\frac{\sqrt{Q_1\bar{u}}}{v_1} \qquad (24)$$

involving volume rate of discharge at 68F, Q_1, wind velocity, $\bar{u}$, and stack gas outlet velocity, v_1. Equations (23) and (24) indicate that the plume rises only a finite distance under the influence of outlet velocity and that this rise is dependent on the quantity of gas discharged into the atmosphere and the wind velocity. Comparison of plume height as indicated by Bosanquet with results of tests made at New York University on model stacks indicated only fair agreement between theory and experiment.

Solution to a Particular Stack Problem

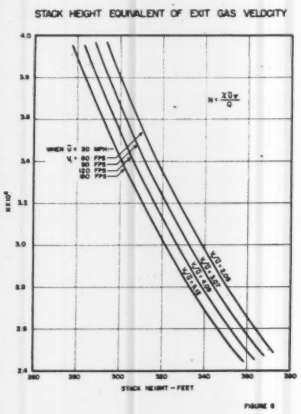
An example problem will indicate the application of the previous discussions to a particular problem of stack design. Suppose that it is desired to determine the various stack heights and outlet velocity magnitudes which are equivalent to a stack with an exit gas velocity of 120 feet per second. Assume that the vertical velocity component is equal to $v_1 x^{-2/3}$ where $v_1 = 120$ feet per second. It may be shown that for small θ

$$x = \left(\frac{v_1}{\bar{u}}\right)^{3/2} \left[\theta^{-3/2} - \left(\frac{\pi}{2}\right)^{-3/2}\right] \tag{25}$$

$$B = 3\left(\frac{v_1}{\bar{u}}\right)^{3/2} \left[\theta^{-1/2} - \left(\frac{\pi}{2}\right)^{-1/2}\right] \tag{26}$$

$$\frac{dB}{dx} = \theta \tag{27}$$

where θ is a parameter whose physical significance is that it represents the angle between a horizontal line and the tangent to the centerline of the plume. Figure 6 is the result when Equations (25), (26) and (27) are substituted in Equations (19) and (21), and the latter two



equations are solved simultaneously. In order to obtain sufficient information, all combinations involving $v_1 =$ 60, 90, 120 and 150 feet per second and h = 285, 300, 315, 330, 345 and 360 were considered. Each curve of Fig. 6 is determined from six calculated points. Reading horizontally across the curves of Fig. 6 at an N value corresponding to $v_1 = 120$ feet per second and h = 300 feet yields additional values of stack height and gas velocity. Since each pair of values obtained in this manner produces a maximum ground level concentration exactly equal to that of a 300 foot stack with a 120 feet per second gas velocity, all such pairs of values represent equivalent stacks.

Conclusions

The results of this paper may be summarized as follows: Equivalent stacks have been discussed and precisely defined. A method of determining when several stacks are equivalent has been given in considerable detail. It has been shown that the method of calculation can be carried out, in some cases, both graphically and analytically. Although the procedure outlined in this paper considers only the special case of velocity rise, the theoretical material presented is general in nature and may be used to determine equivalent stacks when density variations also produce a rise of the plume.

The present method requires a prior knowledge of the analytical form of both the concentration function for a continuous point source and the plume centerline equation. In the example problem cited in this paper, Sutton's concentration function and a modified Sutton centerline equation were used. It is not to be implied that these are the best choices that could have been made. They do, however, represent two possible choices and must, therefore, be considered in any attempt to define the most desirable set of equations to use. At the present time, the author is investigating the use of equations (23) and (24). Their use has been found to increase many fold the arithmetic required in the solution of any particular problem.

Acknowledgments

The author wishes to acknowledge the aid of the various members of the Engineering Studies and Calculations Group of the Electric Test Department.

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Economic and Engineering Considerations in the Design of Stacks for Good Gas Dispersion

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In the not too distant past, the engineer's job in selecting a proper stack was a comparatively simple one. All he had to do was to satisfy himself that the stack was providing sufficient draft for the particular boiler, or boilers, it was to serve and that it was adequate from a structural standpoint. We have now reached the point where the sole function of a power plant stack is the dispersion of the products of combustion in the most effective and desirable manner. This apparent simplification of purpose has resulted in creating a very complex problem which requires the careful collection and analysis of a large mass of related data.

Several papers dealing with this subject have already been presented before this association in previous meetings.[1][2] It is not the purpose of this paper to present needless repetition and, consequently, some of the many problems that face the designer will be assumed as solved. We shall talk about a hypothetical plant consisting of a number of 100,000 kw generators. This specific size is used in this paper as a convenient base unit for analysis and expression of quantities. Costs will be expressed in terms of relative units instead of dollars. These units have been adopted for convenience of illustration and the principles involved can be explained more readily in this fashion.

In our analysis, we will assume that each boiler will be provided with its own stack, which has become common practice for boilers supplying generators of the size used in this example; that the arrangement of the induced draft system with its dust collectors will be along the "ranch type" design and that the stack will be supported at the ground level. It will also be assumed that the soil conditions are such that the stack will be founded on piles and that the piles will not be subjected to up-lift under any load conditions.

The range of fuels, the amount of excess air, allowance for air leakage, estimates of gas temperature, and the maximum cfm of flue gas per boiler having been determined, we start out by making an estimate of the approximate stack dimensions.

Approximate Stack Dimensions

Until recently, the stack diameter was chosen to give a minimum practical friction loss. In many cases, this resulted in a stack velocity of the order of 50 fps. With the necessity for higher and higher stacks in order to achieve proper dispersion of the combustion products, the designer will find that friction loss is no longer the proper criterion for selection of the optimum diameter. In order to get reasonable relations between stack diameter and height for structural considerations, he will have to choose a much larger diameter which, in turn, will materially reduce the flue gas velocity through the stack barrel. In order to provide the necessary emission velocity, nozzles may be introduced at the top of the stack.

The relation between stack diameter and height is especially important in the case of a self-supporting steel stack. In the past, this type of stack has been designed largely by means of arbitrary values which substituted a larger factor of safety for accurate knowledge of the subject. Recent developments have shown that resistance to ovaling, natural frequency of vibration, and buckling strength should be investigated and that considerable work remains to be done on these three subjects. An approximate estimate of required height can be made by the use of the earlier Bosanquet and Pearson formula.[3] For purposes of our illustration, we shall assume that an inside diameter of 20 ft. and a height in the neighborhood of 300 ft. have been established as tentative stack dimensions.

Type of Stack Construction

Three types of stack construction will be considered. First, self-supporting steel stacks with gunite lining; second, reinforced concrete stacks with independent brick lining; third, brick stacks with independent brick lining. Costs for the first type will usually have to be worked out by the designer, while costs for concrete and brick stacks will have to be obtained from stack constructing companies. In order to get a sufficient number of points for plotting, it will be advisable to design stacks for the preliminary height as well as for stacks 50 or more ft. higher and, possibly, 50 ft. lower. Foundations for all of these cases will have to be worked out and we can then plot the results in the form of three curves as shown on Fig.1. From this graph, it appears that self-supporting steel stacks and their foundations can be constructed economically up to a certain height, approximately 275 ft., but above that height, reinforced concrete stacks become more economical, while the cost of the brick stacks remains out of range for any height. However, before a true economic analysis can be made, not only the initial cost, but also possible maintenance costs, must be taken into account. This is a point on which opinions can vary over a

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wide range. Maintenance costs on gunite-lined steel stacks have been established, and many utilities have concluded

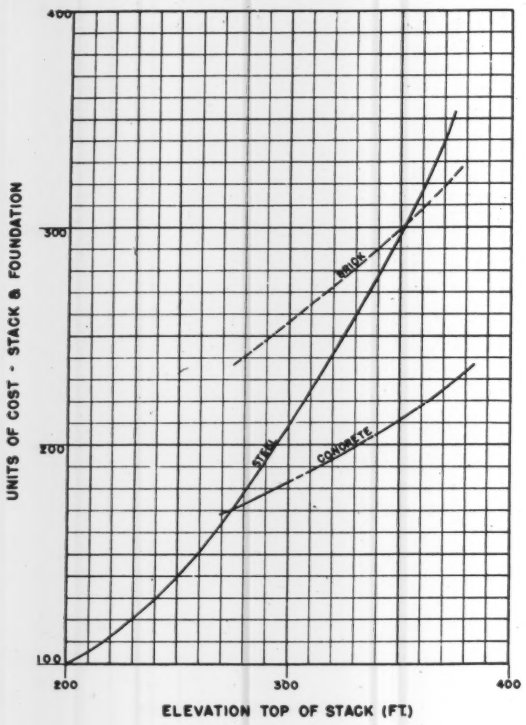


Fig. 1. Comparison of cost—steel, concrete, and brick stacks, various heights.

that the maintenance of gunite is negligible while maintenance of the steel consists largely of the cost of exterior painting. There seems to be considerable controversy as to the amount of maintenance on concrete stacks. Some users have found that their maintenance has been negligible while others have had considerable expense. Local climatic conditions, stack gas temperature, and materials of construction affect the required amount of maintenance work. Brick stacks are known to stand up well for the first 10 to 15 years of service, but after that time require extensive and very costly repairs. Another point is the possible necessity for future extension of the stacks in order to keep up with ever-increasing demands from air pollution authorities and the public or the possibility of a change in character of the territory surrounding the plant. While any provision for future extension is costly, it is easily accomplished on a self-supporting steel stack and the time required for such work is usually confined to five or six weeks. The future extension of a concrete stack, while possible, is not particularly desirable and the shutdown time required changes from weeks to months. The same considerations apply to brick stacks. Outage time for maintenance follows a similar pattern. The capitalized value of annual maintenance averaged over a 30-year period has in one instance shown that it might run approximately 3 per cent of the total cost of stack and foundation for a steel stack, from 5-16 per cent for a concrete stack and approximately 8 per cent for a brick stack.

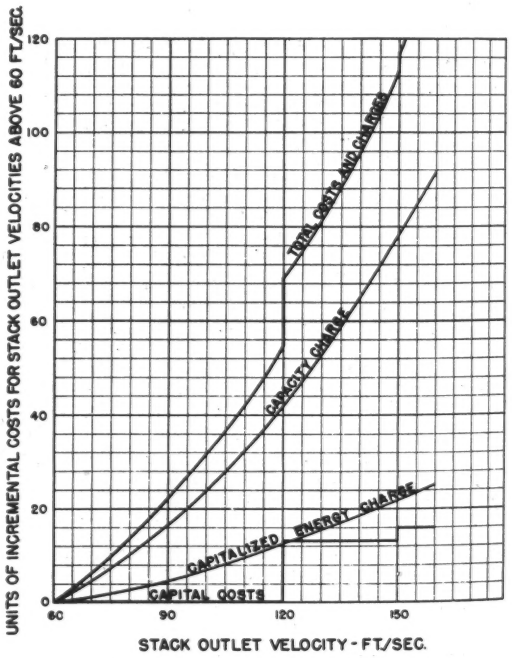
If the preliminary design height happens to fall below the critical point where the steel stack and concrete stack curves intersect, the answer is evident, but if the design height should happen to fall a short distance to the right of this intersection point, a decision must be made whether the saving in initial cost effected by the use of a concrete stack is worth the risk which higher maintenance costs and prolonged outage time may bring.

Stack Outlet Velocity

In past years, it has been recognized by a large number of designers that a high gas outlet velocity has some distinct advantages, especially in cases where there are limitations to the height of stacks due to their proximity to airports. These higher exit velocities, which in effect act like an extension to the stack, remained under 100 fps until a few years ago; however, recently some plant designers have chosen higher velocities.

From wind tunnel tests conducted by Dr. E. F. Wolf and the writer in 1941,[7] and from subsequent observations of the prototype installation, it was learned that an outlet velocity of 60 fps prevented the flue gases from being caught in the stack vortices with wind velocities up to approximately 35 mph. Sixty fps was the outlet velocity used in earlier installations; however, velocities of 90 fps give protection for wind velocities reasonably in excess of 35 mph.

Fig. 2. Comparison of cost—various outlet velocities. Top of stack elevation 300.



The choice of outlet velocity has to be influenced to a large degree by economic considerations. On the basis of accepting 60 fps as an absolute minimum, incremental costs for various outlet velocities and two or three different stack heights should be computed. Taking capitalized Energy Cost, Capacity Charge, Cost of Fan, and Cost of Motor into consideration, we arrive at curves similar to those shown on Fig. 2. One can readily see that the higher outlet velocities represent a sizeable investment.

Dust Collector Installation

Before making any calculations on discharge and dispersion, the engineer must decide what type and size of dust collection apparatus must be considered. For the purpose of this illustration, it is assumed that over-all efficiencies in excess of 95 per cent are specified for a plant of this size. Some manufacturers of electrostatic precipitators offer large electrical units exclusively, but the engineer will do well to prepare preliminary layouts for a high efficiency installation to determine whether the necessary space is available for the required low gas velocity and for proper distribution of gases to and from such large collectors. If he makes a conservative choice of gas velocity through the collectors, let us say 6.5 fps, in order to insure sustained high efficiency performance, he may find that the width required for such an installation may easily exceed the width of his boiler room. Such a layout would get him into trouble on the second and all following units. In such case, where width is the limiting factor, a solution may be found by the use of a series-combination unit with a mechanical dust collector in the leading position and an electrostatic precipitator in the trailing position. While the cost of such an installation is quite high, in the neighborhood of half a million dollars for larger units, it has the advantage that high over-all efficiencies can be maintained without difficulty, and that in case of an interruption to the electrical precipitator, the mechanical unit is still capable of collecting a large percentage of the flue dust.

For our example, we will assume a mechanical dust collector of 83 per cent efficiency, followed by an electrostatic precipitator of 85 per cent efficiency, resulting in over 97 percent over-all efficiency for the series-collectors.

Maximum Concentrations at Ground Level

It is now possible to compute maximum dust concentrations at ground level by means of a modification to the latest Sutton formula, which even permits taking gas outlet and wind velocities into account. Dr. McDaniel will present a paper on this subject.[6] However, while boiler load and outlet velocity may be kept constant by the power plant operator, he has no control over wind velocity, and it is a well known fact that the wind remains constant neither in intensity nor direction. This results in a much better actual dispersion than the theoretical formulas would indicate.

Under the climatic conditions which generally prevail in this area, a suspended dust concentration of 5.5 mg/1000 cu. ft. does not generally produce a visible haze; therefore, let us use this value as the maximum suspended dust concentration at ground level at any point in line with the gas trail emanating from the stack.

The engineer must gather data on existing plants in order to be able to apply a correction factor to the theoretical values. Too little work has as yet been done on this phase to permit any definite conclusions. From the few observations made in one location, an average factor of 1:4 seems to be indicated, and for purposes of this study, this factor will be used.

The above mentioned modified Sutton formula also permits the calculations of SO_2 concentrations at ground level.

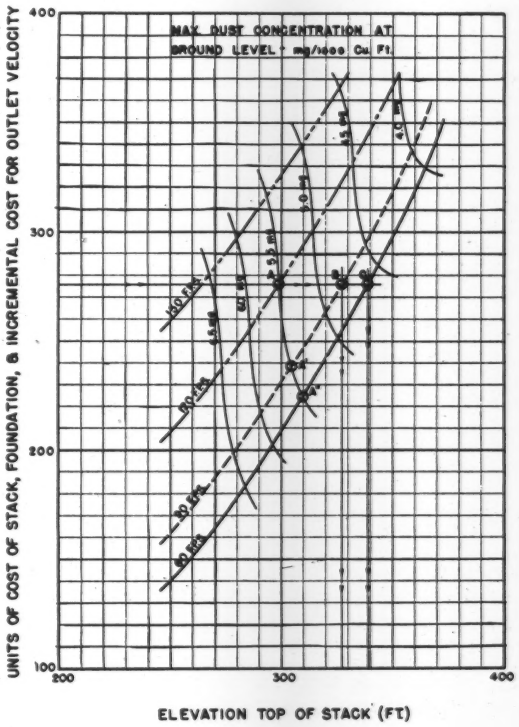
Concentrations of 2 ppm are the lowest which can be detected by most people with an acute sense of smell, and British papers have suggested a maximum acceptable limit at ground level of 1.9 ppm.

Again for illustration, we shall choose an arbitrary relative value, let us say Unity. The absolute value will depend upon the sulfur content of the particular fuel which is used.

Stack Height Versus Outlet Velocity

We should now study the economic relation which exists between stack height and outlet velocity. On Fig. 3,

Fig. 3. Comparison of various heights, outlet velocities and dust concentrations. Steel stacks.



cost curves for steel stacks, including foundations, have been plotted for four outlet velocities. The solid line represents the base cost of a gunite-lined steel stack, and since 60 fps has been assumed as the minimum outlet velocity, no extra charges have been added. The three curves above, for 90, 120, and 150 fps represent the sum of the stack costs plus the incremental costs for the raised outlet velocity.

We have also added a family of intersecting curves to this graph which represent values for maximum dust concentration at ground level, computed by the modified Sutton formula.

We note that the 5.5 mg per 1,000 cu. ft. dust concentration curve intersects the 120 fps stack curve at Point A, corresponding approximately to an elavation of 300 ft. and 276 units of cost. If we follow this dust concentration curve on down to Point A′, we find that this intersection with the 90 fps stack line indicates a stack elevation of 305 ft. at a cost of 239 units. Following this curve further on down to Point A″, we find that a stack built to elevation 310 ft. with 60 fps outlet velocity would give us the same maximum dust concentration for 225 units of cost, representing a saving of 14 units over Point A′, and 51 units over Point A.

Going back to Point A and proceeding horizontally, on a "cost line," to the right, we find that this horizontal line intersects the 90 fps line, at Point B, at an indicated elevation of 327 ft. and the 60 fps line, at Point C, at an elevation of 339 ft.

Since the full benefit of outlet velocity can only be obtained when the unit is working at full load, whereas additional height of stack will be beneficial at any load, it can be seen that, for a given amount of money, it is more economical to invest it in additional stack height rather than to spend it for additional outlet velocity.

There is, however, a further benefit which can be derived from additional stack height. As we travel along a horizontal "cost line" from left to right, we are intersecting dust concentration curves of lower and lower values. From the graph, we can read a dust concentration of 4.8 mg at Point B and 4.6 mg at Point C, representing an improvement of 12½ per cent and 16 per cent, respectively.

Geographical Location

The next important consideration is the geographical location of the plant. By superimposing the proposed location of the stack (or stacks) on a map of the surrounding territory and by drawing circles of maximum concentration of suspended dust in the air at ground level, it can be seen whether these circles strike any built-up areas. Serious consideration must also be given to the possible future development of the area. Is it going to be largely industrial or is there a chance of further residential expansion? In connection with this, the prevailing winds must be studied (Fig. 4).[3] It is not sufficient to rely on the fact

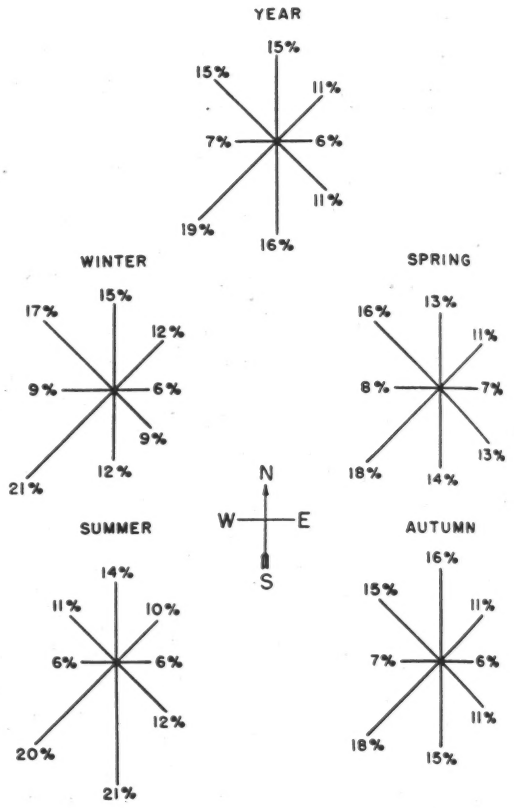


Fig. 4. How the wind blew. Percentages of time for each direction.

that prevailing winds might, for example, be in a northeast direction for one season of the year and, possibly, southwest direction for another season, but it is necessary to study cumulative wind roses for the four seasons of the year.

If these wind roses should indicate that the wind blows toward a development, let us say, 40 per cent of the time during the outdoor seasons, this, too, will be a definite indication that special attention must be paid to the flue gas dispersion problem. Prevailing wind velocities in critical directions and frequency of atmospheric inversions must also be taken into consideration. If this check of the geographical location reveals that the original assumptions still hold good, then it is time to proceed with the next step in the analysis of the problem.

Size of Ultimate Plant

The picture is not complete unless we take the size of the ultimate plant into consideration.

For example, we shall start with a six-generator plant of 600,000 kw ultimate capacity but shall also investigate what happens if additional generators are added beyond the original layout.

[3]From *OUR CLIMATE-MARYLAND and DELAWARE*, issued by Maryland State Weather Service, 1941.

Based on the previously mentioned computations and the values shown in Fig. 3, we can present the results in tabular form. We can now establish how many generators can safely be installed for a given stack height and at the same time determine what type of dust collector installation will give us the necessary protection.

TABLE I

Stack Height for six generators = 600,000 kw
Assumed maximum permissible concentrations:
SO_2 = 1 Unit
Dust = 5.5 mg/1000 cu. ft.

No. of Generators	Top of Stack at El. 300′					
	1	2	3	4	5	6
SO_2—Units:	.16	.32	.48	.64	.80	.96
Dust: mg/1000 cu. ft.						
Mech. Collectors Only	2.20	4.40	6.60			
Series-Collectors			1.32	1.76	2.20	2.64

From Table I, we can see that Mechanical Dust Collectors only would be adequate for the first two generators, but it would be necessary to install series collectors for each generator by the time the third one goes into operation to meet the assumed dust limitations. The stack height (El. 300′) is satisfactory for six generators.

Let us further assume that the plant will be expanded to eight generators, with a total capacity of 800,000 kw.

TABLE II

Stack height for eight generators = 800,000 kw
Assumed maximum permissible concentrations:
SO_2 = 1 Unit
Dust = 5.5 mg/1000 cu. ft.

No. of Generators	Top of Stack at El. 300′						at El. 345′	
	1	2	3	4	5	6	7	8
SO_2—Units	.16	.32	.48	.64	.80	.96	.88	1.00
Dust: mg/1000 cu. ft.								
Mech. Collectors Only	2.20	4.40	6.60					
Series-Collectors			1.32	1.76	2.20	2.64	2.44	2.78

Table II indicates that the addition of the seventh and eighth generator, for an ultimate capacity of 800,000 kw, would require an extension of all stacks to El. 345′. With a Series-Collector installation, the dust emission poses no problem even for the eight-unit plant.

Selection of Stack Height and Dust Collectors

The engineer can now choose between several combinations:

1. He may decide that the ultimate capacity of the plant will never exceed 600,000 kw. In this case, stacks to El. 300′ are satisfactory.
2. An increase in size of the ultimate plant to 800,000 kw must be expected and he can then
   a. build all stacks to El. 345′ or
   b. design the stacks for El. 345′ but build them to El. 300′ only for the first six generators. All stacks must then be raised with the seventh unit. In that way, he can effect some saving in capitalized costs.

3. He must provide the necessary space for Series-Collectors and can either
   a. install the series-collectors from the start, or
   b. defer the installation of electrostatic precipators until the third generator goes into service.

Which of these combinations he chooses will depend entirely on his particular problem and how it is affected by all the aforementioned points.

Wind Tunnel Tests

There remains, however, one further step before the engineer can feel reasonably sure that the foregoing analysis has really given him the correct answer.

As mentioned before, the theoretical formulas which have been used to determine concentrations at ground level are all based on uniform air movement and do not allow for disturbances created by the power plant building, and possibly adjacent structures. These structures will tend to deflect the air currents and create turbulent zones in the wake of the buildings. Unless the stack gases are discharged well above the turbulent zone, the concentrations at ground may occur at a much shorter distance and at greater intensity than those indicated by the formulas.

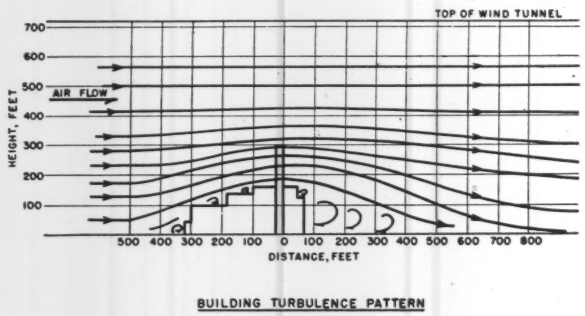


Fig. 5. Wind Tunnel Tests

The engineer will do well to resort to simple wind tunnel tests[7][8] to study the turbulence pattern of the power plant structures (see Fig. 5) to assure himself that the top of the stack is high enough to keep the gases out of any possible downdraft. Only after he has confirmed his stack height by such tests, can he proceed with reasonable assurance that his theoretical calculations will give him a fairly close answer.

Conclusions

The design of a stack for a large power plant is no longer a simple structural problem, but one which is largely governed by attempts at proper gas dispersion and economic considerations. Type of stack construction, stack height, stack outlet velocity, maximum concentrations at ground level, type of dust collector installation, geographic location of the plant, and size of ultimate plant, all must be weighed before a definite recommendation can be made. As a final step, the engineer must check his findings by wind tunnel tests in order to avoid grave errors.

It is fully recognized that the foregoing discussion gives a general analysis of the subject only, and it is intended rather as an outline which must be varied to meet each individual case. Much experimentation and carefully collected data are needed in each specific case before the engineer will be able to undertake the design of modern stacks with an adequate sense of assurance.

Acknowledgments

The authors wish to express their appreciation to Messrs. E. F. Wolf, W. N. McDaniel, A. H. Plantholt, and Miss Phyllis Crichton, of the Electric Test Department, and Messrs. G. S. Harris, W. MacWilliams, Jr., M. Tomko, and L. D. Homan, of the Electric Engineers Department, of the Consolidated Gas Electric Light & Power Company of Baltimore, for their valuable assistance and suggestions.

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The Use of Averages in Air Pollution Meteorology*

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Introduction

The dispersion of smokes and gases in the atmosphere is a complex problem for which we are not likely to find a universally applicable solution in the near future. The existing mathematical treatments of the process are tedious, and accurate empirical data on which the base values of the parameters contained in the formulae are still not available in quantity. Thus, it is quite natural for one seeking a practical solution to a specific problem to attempt to use some average values giving a quick general result, rather than undertake a complete investigation.

The most widely-used papers on atmospheric dispersion, Sutton[1] and Bosanquet and Pearson,[2] give average values for the parameters in their respective formulae. A casual review of the papers seems to suggest that these values are intended to represent the usual or most common meteorological conditions. At any rate, there is little doubt that this interpretation prevails among the majority of readers. However, these average values were derived from a number of sources and merely represent some sort of mean of the meager data available. In neither case is there any direct indication that the term "average" may properly be interpreted as "most probable."

In view of the fact that many specific pollution problems are closely associated with the frequency of occurrence of undesirable conditions, it is important to establish the relative frequency of the various dispersion regimes. Data are still too spare to permit a general assessment of average conditions, but it is felt that the intensive two-year study of gustiness at Brookhaven National Laboratory[3] does emphasize some important aspects of the problem.

The Brookhaven gustiness classification has been fully described in prior publications,[3,4] and the brief resume given below will suffice for the present purposes:

A —Very light winds, pronounced instability

B_2—Light winds, pronounced instability

B_1—Moderate winds, moderate instability

C —Moderate to strong winds, neutral stability

D —Wide range of winds, pronounced stability

Before proceeding to the discussion of climatology, it is necessary to establish as completely as possible the relationship between the Sutton and Bosanquet "averages" and the gustiness classes. In the former case this is straightforward; the "zero gradient conditions" in the Sutton paper correspond to the C gustiness classification. It is more difficult to deduce the relationship with the Bosanquet average, since it appears to be an approximation derived from several sets of data. However, the Brookhaven experience indicates that maximum concentrations at a distance of 10 stack heights would be expected with gustiness near the dividing line between B_1 and C.

Gustiness Climatology

The wind speed and the vertical temperature structure are two of the most important factors influencing atmospheric turbulence. It is therefore worthwhile to note the relationships between the overall mean values of these parameters and those of the individual gustiness classes. This is accomplished in Figs. 1 and 2, in which the frequency distributions, the means associated with the gustiness classes, and the overall means for wind speed and temperature lapse rate are shown.

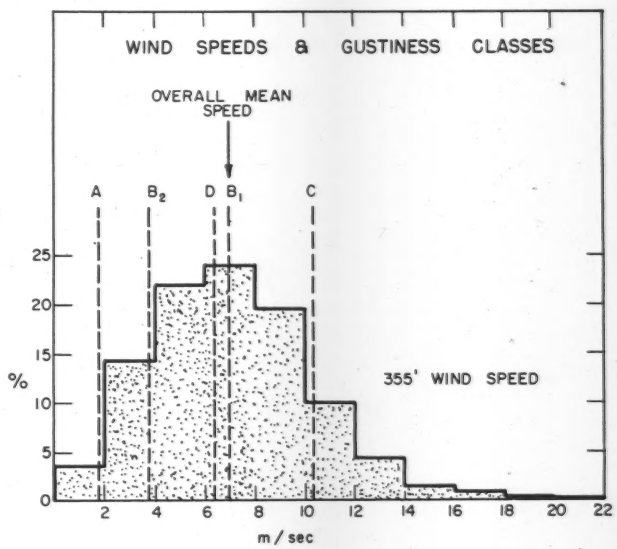


Fig.1

The results are not particularly conclusive. The overall mean wind speed of 7.0 mps coincides exactly with that of the B_1 classification and is very close to that of the D gustiness. The A, B_2 and C groups have mean wind speeds very different from the overall mean value. However, the relationship between lapse rate and gustiness does not show a similar pattern; the overall mean temperature difference of +0.3°C. is not close to the mean value of any individual class, although the C and D values are the closest.

*Research carried out under the auspices of the U. S. Atomic Energy Commission.

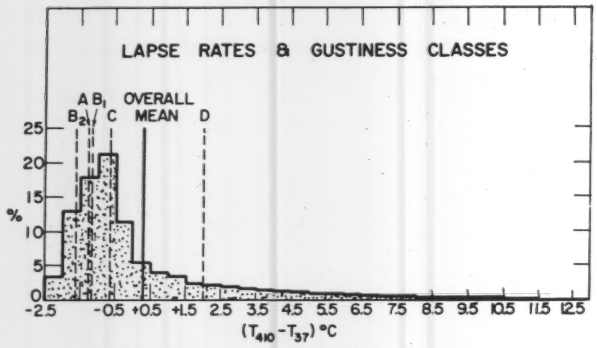
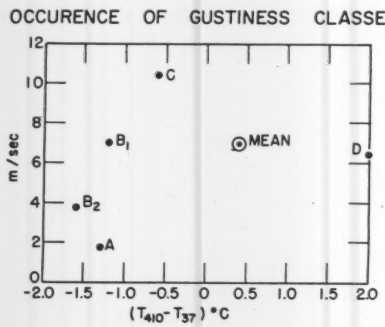


Fig. 2

A direct combination of the wind speed and lapse rate data does not clarify the situation. In Fig. 3, where the wind speed values are plotted on the ordinate and lapse rates on the abcissa, and the gustiness classes are located according to both mean values, we find that the mean of all data does not suggest that any of the gustiness classes represents the combined average.



(1) RELATIVE DISTANCE OF GUSTINESS CLASS TO MEAN		(2) % OF OCCURENCE	WEIGHTED DISTANCE (1) / (2)
C	33	14	2.3
D	40	40	1.0
B_1	41	42	1.0
A	54	1	54.0
B_2	55	3	18.3

Fig. 3

A clue to the true state of affairs is given by weighting the distances of the gustiness classes from the overall mean according to their frequency of occurrence. This has been presented in the table appearing in the lower portion of Fig. 3, and although the values are arbitrary in the sense that they are dependent on the scale of the graph, it is apparent that B_1 and D become the most significant classifications.

Consideration of the gustiness classes from the point of view of probability of occurrence produces more satisfactory results. In the two-year record, the B_1 and D classifications together account for 82% of all hours as is shown in Fig. 4. A further breakdown into night and day hours (Fig. 5) shows that a typical (or average) day at

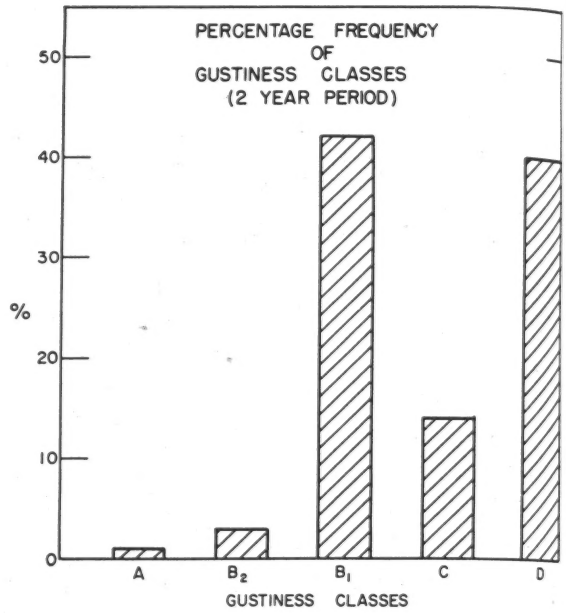


Fig. 4

Brookhaven has B_1 gustiness during the daytime and D gustiness at night, with a relatively low probability of any other type. It is also interesting to note that the seasonal variation of the gustiness types is small.[3]

It is certain that calculations of stack dispersion based on parameters appropriate for the C or B_1-C borderline conditions would be likely to give a wholly unrealistic representation of typical conditions at this site. In the first place, during 40% of all hours the D gustiness prevails, generally accompanied by a temperature inversion. During such conditions ground-level concentrations from an elevated source would be non-existent, owing to the lack of vertical turbulence. In 42% of the remaining hours, maximum concentrations found at ground-level would be typical of the B_1 case, rather than the "average" C case.

Hypothetical Case Studies

Whether the values and distances of the typical maximum concentrations would be higher or lower than the average prediction depends on the exact nature of the source itself. As an example, to show that the use of an "average" might be misleading in either overestimating or underestimating concentrations, calculations have been made on hypothetical cases using Sutton's diffusion equation[1] and the Bosanquet, Carey and Halton[5] "effective stack height" formula. The calculations were based on the following data:

1. Three stack heights, 100, 50 and 25 meters.
2. Mean wind speeds for three gustiness classes, B_2, B_1, and C (see Fig. 1).
3. Values of C_y, C_z and n for the Sutton equation, derived from Brookhaven data, which are signific-

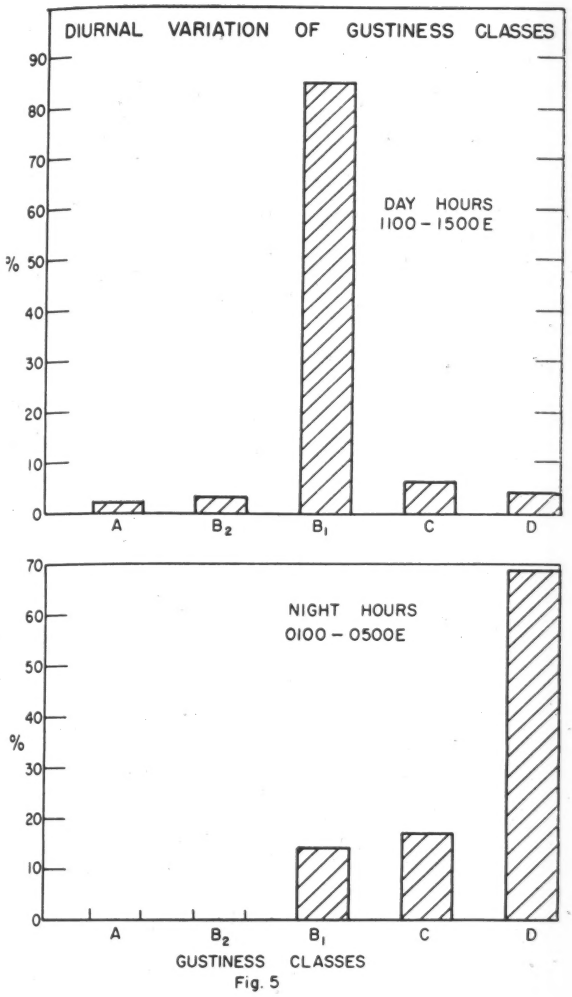


Fig. 5

antly different from the original values, but are not yet ready for publication.

4. A rate of *pollutant* emission of 50 gm/sec. Two types of *total* effluent are assumed: a typical hot, large-volume emission resulting in 100, 50 and 10 meter increases in effective stack height for the B_2, B_1 and C classes respectively, and a cool, small-volume emission for which increases in effective stack height are negligible.

The results of these calculations are summarized completely in Table 1.

The well-known effect of an increase in the heat and volume of the effluent in producing lower maximum concentrations at greater distances from the source is immediately obvious from the table. It is also apparent that the higher stacks produce lower maximum concentrations.

These calculations have some additional implications from the point of view of the design of plant facilities. If the plant were to have a small volume of cool effluent, the use of "average" (C case) calculations would underestimate the maximum ground concentrations of the pollutant during the daylight hours. This would be true for all stack heights. However, with a large volume of hot effluent, the underestimation would apply only to the 100 meter stack; the maximum concentrations from the 50 and 25 meter stacks would be lower than predicted.

Such differences result from the complex interaction of diffusion and stack parameters, but the predominant effects can be described. In the case of the cool, small-volume emission, the actual stack height is also the effective stack height under most conditions, so that the diffusion parameters are of the greatest importance. Thus, the more stable C case, associated with high winds, produces lower maximum concentrations. However, a large volume of hot effluent will rise above the actual stack top, especially in light winds, and can reverse the normal distribution of maximum concentrations. This effect is likely to be observed if the rise is of the same order of magnitude or greater than the actual stack height.

Conclusions

The data summarized herein show very clearly that "average" conditions as presented in some of the more important papers on atmospheric dispersion should not necessarily be considered as "most probable." In the case of the Brookhaven site these "average" conditions occur less than 20% of the time. It is believed that the distribution of dispersion conditions observed at this site is representative of many areas. The "C" gustiness classification is largely associated with the cloudy skies and high winds of the typical storms, and the number of such storm passages in this area is equal to or greater than that of most of the United States. This contention is supported by data from Oak Ridge National Laboratory, where both the terrain and the measuring techniques were different. Gifford[6] has stated that a series of neutral-lift balloon tests showed distinct gustiness patterns similar to Brookhaven's in type and frequency of occurrence.

If a rough approximation of effluent concentrations is needed for a specific stack problem, a minimum of two separate calculations should be made. One should be based on the B_1 gustiness and the other on the D; the latter will of course give ground-level concentrations only with very low stacks or high terrain features. The two sets of calculations should be representative of 80% of the hours in many localities.

A complete meteorological investigation should include detailed consideration of the concentrations resulting from all gustiness classes and certain transitory phenomena, as well as their relative frequency of occurrence. Plant aerodynamics, terrain and the nature and tolerance limits of the effluent are obviously important, and also must be carefully evaluated.

TABLE 1. Typical Maximum Concentrations and Distances for Various Stack Heights and Gustiness Classifications

STACK HEIGHT (meters)		100		50		25	
		Hot & Large Effluent	Cool & Small Effluent	Hot & Large Effluent	Cool & Small Effluent	Hot & Large Effluent	Cool & Small Effluent
C	Concentration (mg/m^3)	.06	.07	.20	.28	.59	1.13
	Distance (Km)	2.2	2.0	1.0	0.8	0.5	0.3
B_1	Concentration (mg/m^3)	.07	.16	.16	.66	.39	2.65
	Distance (Km)	1.1	0.6	0.6	0.3	0.5	0.1
B_2	Concentration (mg/m^3)	.09	.36	.16	1.43	.23	5.74
	Distance (Km)	1.0	0.5	0.9	0.2	0.6	0.1

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The Vertical Distribution of Atmospheric Properties and Air Pollution*

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Introduction

For dispersion of gases and particulate matter from concentrated point-, line-, or area sources, we depend primarily on eddy diffusion. By comparison, molecular diffusion and sedimentation of particulate matter play a neglible role, except perhaps in the case of large dust particles that have a limited life as suspensoids in the atmosphere (5).

Moreover, perfectly laminary flow of air in which molecular diffusion would be important, is extremely rare near the ground. It is easily observed that the dispersive power of the air is subject to wide variations in degree, thus the turbulence of the air flow must likewise vary over a wide range.

Two major types of turbulence are recognized: 1) the thermal, 2) the mechanical turbulence. The thermal turbulence results from a specific thermal structure of the lower layers of the atmosphere to which we will confine our considerations. Mechanical turbulence is induced by the roughness of the ground with all its obstructions to the air flow.

According to M. E. Smith (8), the thermal type is characterized by a wind-direction record whose amplitude during one hour exceeds 90° and fluctuates rapidly and irregularly. By contrast, the mechanical type shows wind-direction records that have small amplitudes (15-90°)with frequent and uniform fluctuations during one hour. A combination of the two types is, of course, observed also.

Thermal Stability Criteria

There is a mutual interaction between the structure of the air flow, i.e., the degree of turbulence, and the vertical distribution of temperature, as will be shown below. Application of the first law of thermodynamics to the case of an air parcel, to which no heat is added and from which no heat is subtracted, leads to the adiabatic lapse rate, a temperature drop of 1°C for a 100-m increase in height for dry air, somewhat less for saturated air.

The temperature of air, that is displaced vertically up or down, changes according to this rate. When existing vertical temperature distributions are compared with the adiabatic lapse rate, the effect of vertical displacement of air on its temperature as compared to that of the environment becomes evident in Fig. 1.

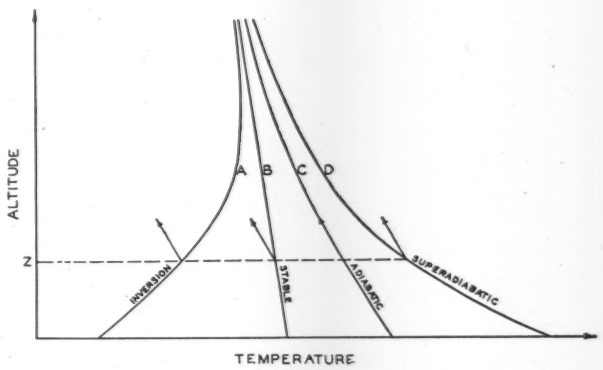


Fig. 1. Effect of upward displacement of air parcels under various conditions of vertical temperature distribution. Also diurnal variation of lapse rate on a clear day.

There, four different temperature distributions are shown: (A) a temperature increase with height (inversion), (B) an ordinary distribution, (C) a temperature distribution which is the same as the adiabatic lapse rate, and (D) a temperature distribution in which the temperature decreases with height at a greater than adiabatic rate.

If we lift a parcel of air from level Z in each of the four cases, the parcel's temperature will decrease according to the adiabatic rate as indicated by the arrows, which are all parallel to the adiabatic slope.

In cases A and B , the temperature of the parcel would be lower than the temperature of the environment that is indicated by the curves. In case C the parcel temperature would be the same as, in case D higher than, the environmental temperature. The temperature difference implies density difference (since the pressures of parcel and environment would be the same), so that positive or negative buoyant forces, i.e., accelerations of the parcel, would result.

The acceleration of the parcel can be expressed by

$$\frac{d^2z}{dt^2} = g\,\frac{T-T'}{T'} = gz\,\frac{\gamma-\Gamma}{T'}$$

where z is height, t time, g acceleration of gravity, T and T′ the absolute temperatures of parcel and environment, $\gamma = -\frac{\delta T'}{\delta z}$ the existing lapse rate, and $\Gamma = -\frac{dT}{dz}$ the adiabatic lapse rate. We see, that in cases A and B in which $T < T'$ and $\gamma < \Gamma$, the acceleration becomes nega-

*Contribution No. 53-5, School of Mineral Industries, The Pennsylvania State College, State College, Pa.

tive, i.e., downward for a lifted parcel or, generally speaking, in the opposite direction of that of the displacement. The acceleration becomes zero for case C, and positive for the superadiabatic case D.

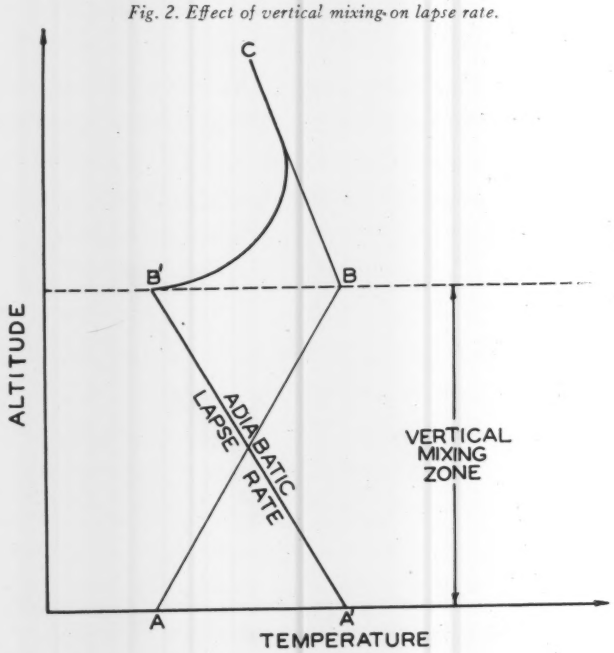
The resistance to vertical displacement in the cases A and B signifies stable stratification; the indifference to vertical motion in case C represents neutral stratification; the assistance of vertical motion in case D is characteristic of unstable conditions. It should be noted that these stability criteria are the same regardless of whether the parcel is displaced up or down .

The different vertical temperature distributions are produced by various meteorological phenomena. For example, inversions at the ground are most often the result of nocturnal radiational cooling of the earth's surface, whereas superadiabatic lapse rates are established by the insolational heating of the ground during day time.

The diurnal variation of vertical temperature distribution on a cloudless day with calm or light winds is well represented by Fig. 1; case A represents the lapse rate from late evening until sunrise; case B lapse rates during morning, late afternoon and evening; case C represents the vertical temperature distribution during forenoon and afternoon; and case D, those during noon and early afternoon.

Radiational and insolational effects on the temperature distribution are generally confined to the lower air layers; farther aloft, the diurnal variations of temperature are small as indicated by the upper half of the four curves in Fig. 1. Among other causes for the various vertical temperature gradients are advection of warm air over cold ground (stable) or of cold air over warm ground (unstable).

Fig. 2. Effect of vertical mixing on lapse rate.



Air Motion and Thermal Stability

If we now consider the air flow and its effect on the vertical temperature distribution, we find that the vertical components of turbulent air flow will tend to mix the air in the turbulent layer. Since the up and down motions of the mixing process cause adiabatic temperature changes, the lapse rates tend to become adiabatic regardless of what they were before turbulent mixing began.

In Fig. 2, the original temperature distribution is given by ABC; after mixing of the air between A and B, the resulting temperature distribution is A'B'C. The ground inversion AB is replaced by a neutral (adiabatic) lapse rate A'B' with an inversion above. In other words, the stirring of the air produces adiabatic conditions, rather than the isothermal conditions that are established in a liquid with previous temperature stratification.

For this reason, the thermal turbulence that is facilitated by unstable lapse rates tends to convert these lapse rates to neutral, i.e., less unstable, conditions. On the other hand, stable thermal conditions have a damping effect on turbulent motion, and turbulence tends to destroy the stable condition.

In this respect it is interesting to note that, according to M. E. Smith (8), it requires a stronger wind to destroy an existing ground inversion, than is necessary to prevent the formation of an inversion under otherwise proper conditions of nocturnal radiation. Thus, the diurnal variation of temperature structure of the lower layers shown in Fig. 1 will be greatly modified if a strong wind prevails, which will maintain near-neutral conditions day and night. Also, overcast skies may reduce incoming and outgoing radiation to such an extent that the lapse rates will not materially change, unless a new air mass is advected.

The suppression of vertical currents and consequent accumulation of air pollutants in stable air does not necessarily mean high concentrations of polluting matter near the ground. Neither does instability near the ground necessarily mean clean air. The pollutant concentration observed depends, of course, on the height and the distance of the source of effluents.

Fig. 3 Schematically depicts the behavior of smoke plumes that may be observed at a point A under conditions of stable and unstable temperature structure. It is shown, that even under unstable conditions, so-called looping (1) of plumes may occasionally bring high concentrations of smoke from elevated sources to the ground, whereas under stable conditions the effluents from tall stacks may remain aloft.

The looping of smoke occurs with wind velocities of less than 20 mph, and the distance from the stack at which the smoke reaches the ground diminishes with decreasing wind speed.

Radiation and Thermal Stability

The case of elevated sources under stable conditions has special potentialities of development. If the stability

is produced by a nocturnal ground inversion of temperature, considerable accumulation of effluents occurs aloft.

Hewson (3) has shown that, when the inversion changes into a lapse condition after sunrise, a turbulent layer is established at the ground. This layer grows upward, and when it reaches the polluted air layer aloft, the pollutants will suddenly diffuse downward and show up in high concentrations at the ground.

According to Fleagle, Parrott, and Barad (2), a similar phenomenon may occur at night, when fog forms in a stable air layer on the ground. The radiative cooling of the top of the fog lowers the temperature there, while the temperature at the ground is, at first, little affected.

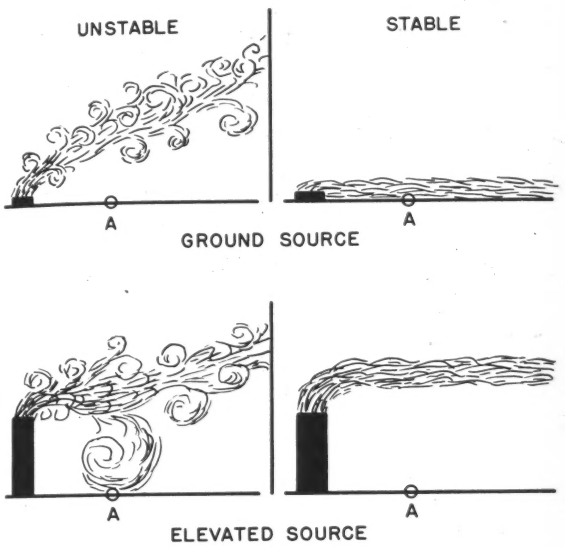


Fig. 3. Schematic diagram of behavior of smoke plumes under stable and unstable conditions.

Thereby the stability of the temperature stratification is reduced, and vertical mixing will eventually start, bringing with it a transport of pollutants from aloft. In turn, the turbulence that develops will tend to establish an adiabatic lapse rate, in this case the lapse rate for saturated air because of the fog present.

An example is shown in Fig. 4, in which soundings of 9 December 1947 made at Hanford, Washington, are reproduced from the above authors. Two of the soundings were made 74 and 4 minutes, respectively, before the fog formed; they show strong ground inversions up to roughly 200 feet, with isothermal conditions prevailing from 200 to 400 feet.

In the third sounding, made 36 minutes after the fog formed which presumably reached to 200 feet, the temperature at that level had already dropped by 2 C degrees accompanied by an equal temperature rise at the ground. The fourth sounding, made 116 minutes after fog formation, shows further steepening of the lapse rate which at that time is practically neutral in the lowest 50 feet, slightly unstable up to 200 feet, with an increasing inversion above that level.

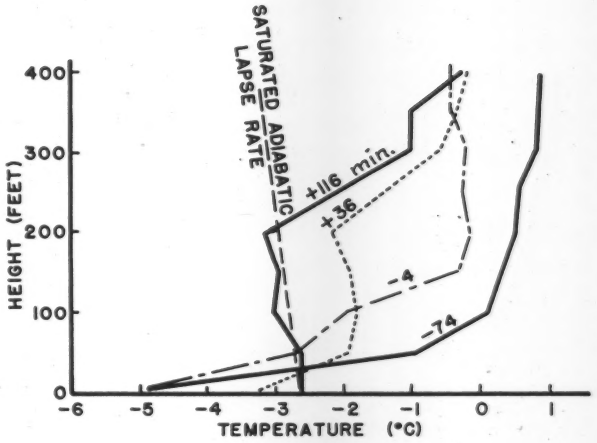


Fig. 4. Vertical temperature distributions from 74 minutes before, until 116 minutes after fog formation (after Fleagle, Parrott, and Barad).

Thus, the air in the lowest 200 feet becomes thoroughly mixed, while the high inversion effectively traps the pollutants from sources in the layer below. We see that, near the ground, air pollution from elevated sources may be large under unstable, small under stable vertical temperature distributions in the lowermost air layer.

For these reasons, it is ordinarily not an easy task to select weather conditions suitable for locating elevated pollution sources by measurements of pollutant concentrations at the surface. For locating ground sources, stable conditions with light winds or calm are ideal. An example of utilization of stable weather conditions for such purpose may be cited.

Example of Air Pollution Survey under Stable Conditions

Inhabitants of an area a few miles east of New Kensington, Pa., claimed annoyance from offending odors allegedly emanating from a pig farm on which garbage was fed to the hogs. However, there were, in the same area, an old still-smoldering garbage dump and a burning trash* dump, which allegedly did not cause any trouble.

When I was consulted in this matter, I reasoned as follows: Most odoriferous substances, in particular decaying organic matter, are sources of condensation nuclei (5). Thus a nuclei counter should be able to find the places of highest concentration in the area under conditions of ground inversion and very light winds or calm. A fog chamber, schematically shown in Fig. 5, was employed for the purpose. An air sample aspirated into the tube serving as a fog chamber is saturated with water vapor from the wet blotting-paper lining of the tube.

*Including some garbage.

Expansion of the air sample by means of a suction pump causes formation of fog on the nuclei present. The greater the nuclei concentration, the denser is the fog; the fog density is measured by means of a light source at one end of the tube and a photronic cell connected to a microammeter at the other end.

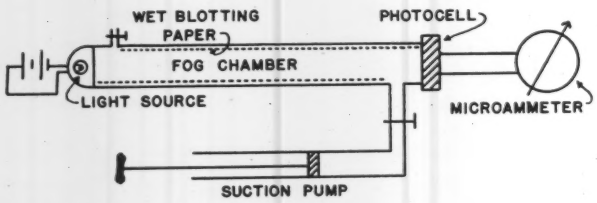


Fig. 5. Schematic diagram of fog chamber used for measurements of the relative concentrations of condensation nuclei.

The day selected for the pollution survey in the area mentioned was 23 January 1953, when this area was within a flat pressure field, and, therefore, light east-northeast winds (between 0 and 2 mph) prevailed. Fig. 6 shows the sectional weather map for 1:30 a.m. EST on that date; the survey area is shown by a crossed square in the center of the map.

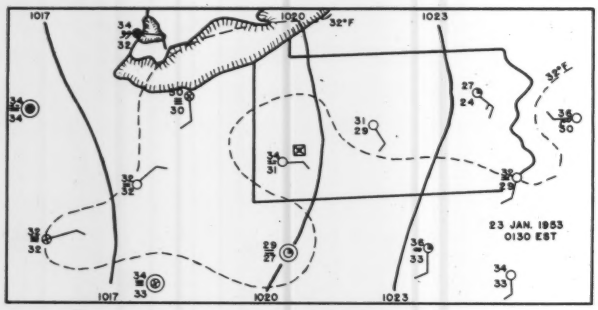


Fig. 6. Sectional weather map for 23 January 1953.

The skies were clear, and radiational cooling at night created a highly stable condition near the surface. The vertical temperature distribution at Pittsburgh is shown in Fig. 7; the solid curve represents the radiosonde data for 10 p.m. (2200) EST for 22 January, the dashed curve for 10 a.m. on 23 January; stable air is indicated for the air layer up to roughly 3000 ft. The survey was made in the early morning and during forenoon.

Fig. 8 shows the results of the measurements made. On the map, the locations at which the measurements were taken are indicated by dots. The concentrations are expressed in terms of per cent of the highest concentration measured (near point B). It is evident that the source of greatest pollution is point B, which is the burning trash dump mentioned above. Point A, the smoldering garbage dump, is second with about 86% of the emission of B.

Because point A was on the lee side of the major source B, as is apparent from the elongation of the isopleths in the west-southwest direction, the measurements at A probably contain some of the effects of B. In order to separate the pollution components at A, one would have to repeat the survey under similar stability conditions with very light winds from a westerly direction.

By comparison with the sources A and B, the concentrations measured in the midst of the feeding hogs at

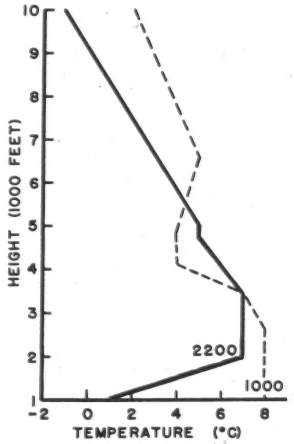


Fig. 7. Upper-air soundings at Pittsburgh, Pa. on 22 and 23 January 1953.

point C are small (58%), especially if we consider that the windward concentrations of 30% are probably "normal". At any rate, it seemed clear to me that the hog farm could not be the major source of pollution in that area.

Inasmuch as the majority of the complainants lived in closer proximity to the burning dump B than to the farm C, i.e., in the southwest quadrant relative to C, and since the prevailing winds in the area are from the southwest, the case was one of mistaken identity.

Electric Properties of the Air

The potentialities for utilizing atmospheric-electric properties as indices of air pollution have been largely overlooked by engineers and meteorologists alike. For this reason, I considered it appropriate to include a brief outline of this topic here.

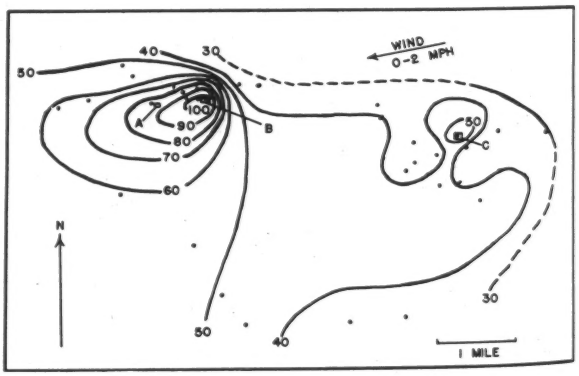


Fig 8. Isopleths of relative concentrations of condensation nuclei (in %) over a small area east of New Kensington, Pa.

The air, generally considered a good electric insulator, is, nevertheless, ionized to a greater or lesser extent by radiations from radioactive matter and gases in the ground, cosmic rays, and other sources (6). These sources cause some gaseous molecules and molecule aggregates of the air to become electrostatically charged, both positively and negatively.

Moreover, the earth's surface is negatively charged, so that an electric potential exists above it. The charged particles, called small ions, thus move in an electric field in which the positively charged ions ordinarily are accelerated toward the earth's surface, the negatively charged ions away from it.

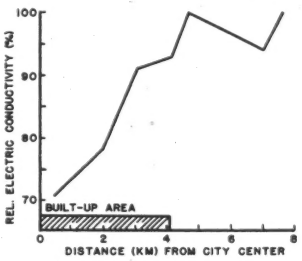


Fig. 9. Effect of city air pollution on electric conductivity of the air in Vienna (after Schilling and Seper).

However, an unaccelerated motion is established by the viscous friction between the ions and the neutral air molecules. The resulting velocity of the ions in a unit electric field, called the mobility, depends, among other things, on the ion mass. The product of ion mobility and concentration characterizes the electric conductivity of the air, so that the conductivity is greater, the smaller (and therefore more mobile) and the more numerous the ions.

Ordinarily, there exists an equilibrium between the ion-forming and ion-destroying and transforming processes. Destruction of small ions is effected by collision between positive and negative ions; transformation of ions occurs when they combine with condensation nuclei, so that these nuclei acquire an electrostatic charge.

Because of their relatively large mass, these charged nuclei, called large ions, have small mobility(*), and their contribution to the electric conductivity of the air is negligible. For this reason, the conductivity will decrease as the concentration of condensation nuclei increases.

When more condensation nuclei are present, there is a greater probability of combinations with small ions and thus formation of large ions at the expense of small ones. Since the concentration of condensation nuclei is a direct function of air pollution (5, 6), the electric conductivity of air is an inverse function of it.

To demonstrate the response of electric conductivity of the air to differences in air pollution, the results obtained by Schilling and Seper (7) are cited. These authors measured the profile of conductivity across the city of Vienna. Fig. 9 shows that the conductivity in the city center is low due to the high concentration of pollutants there, and increases with distance from the center.

Considering the fact that the voltage drop over a length of wire is greater the higher the resistance, i.e., the lower the conductivity of the wire, it is easy to see that the same relationship must exist between potential gradient and conductivity of the air (6).

On the average, the fair-weather potential gradient near the earth's surface amounts to about 130 volts per meter.

Under disturbed conditions, such as during rain, snow, and thunder storms, the potential gradient may rise to several thousand volts per meter, and the field direction may be reversed. The potential gradient decreases rapidly with increasing height above the surface.

In industrial areas, such as at Kew in England, the average potential gradient is about 400 V/m, whereas in localities with clean air it may be as little as 50 V/m. The variation of potential gradient with the amount of air pollution can also be demonstrated by the measurements made in Vienna by Schilling and Seper (7).

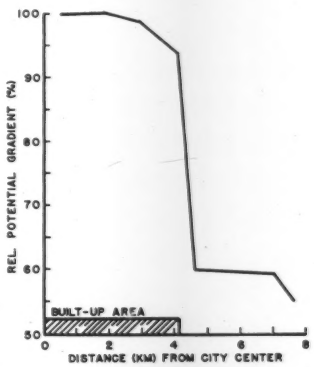


Fig. 10. Effect of city air pollution on electric potential gradient in Vienna (after Schilling and Seper).

Fig. 10 shows that the potential gradient diminishes from the center toward the periphery of the city and drops in the surrounding countryside to less than 60% of its midcity value.

The atmospheric electric properties are not difficult to measure; particularly, potential-gradient measurements can easily be made with small portable instruments (4). The atmospheric-electric elements are, however, subject to diurnal and seasonal variations in addition to those produced by variations in air pollution.

For this reason it appears that continuous records would be suitable for appraising, for example, the effectiveness of pollution-control measures over a longer period of time. In this respect, atmospheric-electric measurements would represent a much more faithful picture than would measurements of visibility or of duration of sunshine, which are used frequently as indices of changes in air pollution.

*Roughly 1/1000 that of small ions (6)

Visibility, aside from the inadequacy of its estimation, is greatly influenced by the relative humidity (5) so that, with constant air pollution, it will be good in dry air, poor in moist air. Likewise, duration of sunshine is largely a function of cloudiness, which is essentially independent of air pollution. It is practically impossible to separate the small effect that smoke may have on the duration of sunshine, particularly in view of the unresponsive instrument used for recording it (9).

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Availability of Good Coal in the United States

By Carroll F. Hardy*

Introduction

The extent and probable life of coal reserves in the United States have been given more consideration in the past few years than they had for many years previously. Of particular concern have been the reserves of coking coal in the Eastern Province. The original survey work conducted by Marius R. Campbell prior to World War I was, of necessity, based on inadequate data in many cases.

From the preliminary work being done by the United States Bureau of Mines and the United States Geological Survey, it has been estimated that at the present rate of production, and with a net recovery of around 25% of the total coal reserves, about 125 billion tons of coal will be recovered in the Eastern Province. At the present rate of production this is equivalent to about 350 years' supply. Whether this estimate proves to be accurate or whether the actual recovery will be greater than 25%, remains to be seen. Further exploration, particularly by the use of core drills, may have surprising results. The use of rotary oil-drilling rigs has already discovered new deposits of coal.

The shortage of industrial coal of all grades, and particularly high-grade coals, during World War II and in the postwar period up to early 1948, led to the fanciful but widely disseminated stories of the depletion of all good coal. For example, the author has been asked repeatedly about the number of years the District #8 coals are likely to last. This is the largest coal-producing district in the United States and has consistently produced around 25% of all the coals used in the country. It also contains the largest reserves of untapped coal in the Eastern Province.

The same type of rumor has been circulated about all other producing districts of the Eastern Province, and it has oftentimes been used as an excuse for using an inferior coal rather than a good one.

Definition of a Good Coal

Every coal-producing district of the United States produces good coals and low-grade coals. The high-grade coals by and large are produced by established mines with adequate mining equipment and with an adequate preparation plant. Poor coals are, in the main, produced by fringe or fly-by-night operators who have no interest in the coal business as such, and have no stake in preparing a uniform high-grade product.

One of the first measurements of a good coal is uniformity of quality. The coal should be consistent as to ash and moisture content, whatever that may be. The minimum of ash, moisture and sulfur which can be maintained in production is most desirable. The coal from any mine will vary somewhat but this variation is insignificant when compared to the variation in quality of coals as bought in some plants. Coals ranging in ash content from around 3% up to 12%; moisture from about 4% to about 15%, and Btu content from over 14,000 down to 11,500 are being used in a hit-or-miss mixture just as the cars happen to arrive at many plants. Even the best automatic controls are taxed to keep up with this type coal supply. Generally, in an industrial plant some effort is made to get uniform quality coal so that the boilers may be operated at maximum efficiency. Naturally, everyone wants good standard uniform coal; that is, coal low in moisture, ash and sulfur, and high in Btu content, but some buyers just can't resist bargain buys of low-grade coal which is always available. Reliability of supply, while it is being ignored to some extent in the present abundance of coal, is a very important factor in determining whether a coal is a good or a bad investment for a plant.

Availability of Good Coal in the Various States

The nine principal bituminous coal-producing states are Alabama, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia. Ninety two and ninety-three hundredths percent of all the coal produced in the United States in 1952 came from these states. In order of tonnage produced, they are:

West Virginia		142,180,000 Tons
Pennsylvania		89,050,000 Tons
Kentucky, East	47,220,000 Tons	
Kentucky, West	21,100,000 Tons	
Kentucky, Total		68,320,000 Tons
Illinois		45,600,000 Tons
Ohio		35,150,000 Tons
Virginia		20,400,000 Tons
Indiana		16,250,000 Tons
Alabama		10,950,000 Tons
Tennessee		4,300,000 Tons

Tennessee ranks below both Utah and Wyoming in tonnage but is included because it is in the Eastern Province. Illinois, Indiana and West Kentucky are in the Interior or Mid-Continent Province; all the rest are in the Eastern Province.

To give an idea of the range of coal values of these states, data has been taken from Report of Investigation #4934, "Analyses of Tipple and Delivered Samples of Coal." Since only the samples analyzed by the Bureau of Mines in 1951 are shown in this report, it may not include the best coal or the worst coal in any particular state. The analyses given are of industrial slack, ranging in size from 2" x 0 down to ⅜" x 0. While it is recognized that modifying, dedusting or double-screening industrial coals in most

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cases improve their analytical value as well as their use value, comparison has been held to the straight slack sizes to put it on a more uniform basis.

West Virginia

In West Virginia, the largest coal-producing state, there are some 1,411 mines with a capacity of 1,000 tons or more per year. About 20% of these mines are strip, although only 8% of the tonnage is produced from strip mines.

The highest Btu coal listed shows 14,530 Btu, as-received, containing 2.3% moisture, 4.7% ash, and 1.1% sulfur. The lowest Btu coal listed shows 11,200 Btu as-received, with 3.3% moisture, 20.8% ash, and 3.8% sulfur.

Pennsylvania

In this State some 2,032 mines of over 1,000 tons per year capacity are listed. About 25% of the tonnage is from strip mines.

The highest Btu coal listed shows 14,170 Btu, as-received, containing 2% moisture, 7.5% ash, and 1.4% sulfur. The lowest Btu coal shows 11,880 Btu as-received, with 4.9% moisture, 16.0% ash, and 2.8% sulfur.

Kentucky

Because the coal in this State is produced from two geological provinces, it is divided into East Kentucky and West Kentucky. The total mines for both areas is 3,169 of over 1,000 tons per year capacity.

East Kentucky

The strip tonnage in this area amounts to about 5% of the total. The highest Btu coal listed shows 13,870 Btu, as-received, with 3.2% moisture, 4.8% ash, and 1.1% sulfur. The lowest Btu coal listed shows 10,920 Btu, as-received, containing 13.4% moisture, 11.7% ash, and 2.4% sulfur.

West Kentucky

This area produced around 21 million tons of coal; nearly half of this was from strip mines.

The highest Btu coal listed shows 12,800 Btu, as-received, with 6.4% moisture, 6.4% ash, and 3.5% sulfur. The lowest Btu coal listed shows 11,420 Btu, as-received, with 7.7% moisture, 14.3% ash, and 4.0% sulfur.

Illinois

There are 298 mines in this state with over 1,000 tons per year capacity. A little over 30% of the coal produced was from strip mines.

The highest Btu coal listed shows 12,400 Btu, as-received, with 6.5% moisture, 9.0% ash, and 2.3% sulfur. The lowest Btu coal listed shows 9,940 Btu, as received, 13.9% moisture, 17.1% ash, and 5.3% sulfur.

Ohio

There are 833 mines in this state with over 1,000 tons per year capacity. About 60% of this production is from strip mines.

The highest Btu coal shows 12,580 Btu, as-received, with 4.1% moisture, 9.1% ash, and 2.7% sulfur. The lowest Btu coal listed for this state shows 10,580 Btu, as-received, with 8.7% moisture, 18.0% ash, and 5.8% sulfur.

Virginia

There are 307 mines in this state with over 1,000 tons per year capacity. Eight and five-tenths percent (8.5%) of the production is from strip mines.

The highest Btu coal listed shows 14,140 Btu, as-received, with 2.6% moisture, 5.4% ash, and 0.7% sulfur. The lowest Btu coal listed shows 13,200 Btu, as-received, with 2.9% moisture, 9.0% ash, and 1.9% sulfur.

Indiana

There are 100 mines listed for this state with over 1,000 tons per year capacity, and a little over 50% of the production is from strip mines. The highest Btu coal listed shows 12,060 Btu, as-received, with 7.9% moisture, 9.0% ash, and 3.4% sulfur. The lowest Btu coal listed shows 9,180 Btu, as-received, with 14.5% moisture, 23.9% ash, and 5.6% sulfur.

Alabama

Seventy-eight (78) mines are listed for this state with over 1,000 tons per year capacity. Thirteen percent (13%) of the production is from strip mines.

The highest Btu coal listed shows 14,110 Btu, as-received, with 4.8% moisture, 2.7% ash, and .7% sulfur. The lowest Btu coal listed for this state shows 10,870 Btu, as-received, with 10.5% moisture, 16.8% ash, and .6% sulfur.

Tennessee

There are 138 mines in this state with over 1,000 tons per year capacity. Ten percent (10%) of the production is from strip mines.

The highest Btu coal listed shows 13,240 Btu, as-received, with 5.1% moisture, 6.1% ash, and 0.9% sulfur. The lowest Btu coal listed shows 11,430 Btu, as-received, with 3.5% moisture, 18.9% ash, and 5.6% sulfur.

As will be shown later, tremendous investments have been made in mining, cleaning and preparation equipment in an attempt to maintain or increase the quality of the coal produced. Nearly 50% of the coal produced today is mechanically cleaned and this percentage has almost doubled since 1944, although it must be pointed out that, particularly in the higher grade seams, mechanized mining and cleaning do not necessarily mean an increase in quality over the former hand-loaded coal. The subject of improving coal through mechanical cleaning is covered more completely in another paper (1).

The Economics of Coal Production

A number of authors have presented data showing how the heating value of coal has steadily declined over the years, even though the price has steadily gone up. This has helped give credence to the myth that all good coals are gone.

Table 1 shows the experience of one plant burning approximately 280,000 tons of coal per year. The plant was modern in 1937 and the equipment is essentially the same today. The same type of coal has always been used in this plant as coal selection is somewhat limited by the

furnace design. It would seem to give the perfect example of decline in coal quality. The average heating value of all the coal used in this plant dropped from 13,790 Btu in 1938 to 12,865 Btu in 1949. The average quality continued to go down for four years after the end of the war and fixed prices. The higher Btu coal was then available and still is. The plant management has not seen fit to buy the higher Btu coals, as operation is satisfactory with the present coals.

The increase in the cost of coal at the plant is also brought out in this table. In the 15-year period the delivered price has increased $4.09 per ton. Freight has increased $1.62 per ton; 75c of it since 1948. The average price at the mines has had a net increase of $2.54, although the price is now $1.00 per ton less than it was at the high point in 1948. Thus, in spite of a freight rate increase of 75c and an increase of $1.05 per ton in the cost of labor, the total cost of coal delivered to this plant in 1952 was 32c less per ton than it was in 1948. The producers have received nothing for their increase in labor costs since 1948 and have in effect absorbed the increase in freight, so that they are receiving the equivalent of $2.12 per ton less than they were at the 1948 rate. The profit or margin in 1948 was only a small part of this $2.12, so the producer has had to cut production costs in many ways to even stay in business. Every item of expense which could be cut has been cut; high cost sections of mines or whole mines have been shut down and maintenance and development work has been deferred to a dangerous extent. Improved mining equipment has helped cut costs in those mines where the operators could buy it.

Progress in Coal Mining and Preparation

According to Ivan Given (2), the coal industry has spent over one billion dollars in underground and surface production facilities in the past 10 years. This has increased the tons per man shift from about 5.2 tons in 1942 to 7.35 tons in 1952. The efficiency in the use of underground machines has risen to the point that only from 45% to 55% of the mine price of coal from these improved mines is now direct labor, whereas it formerly ran from 65% to 75%. Preparation plants and service facilities total about another billion dollars. The interest on this $2 billion investment at 5% is $100 million per year which must come out of the realization. It amounts to about 20c per ton on the basis of the 1952 tonnage.

As was recently pointed out by Dr. C. J. Potter (3), with the tonnage off about 28% from the peak year of 1947, and with prospects of further decreases, many coal operations have had to go out of business. Stronger elements, as mentioned above, have made major investments in mining and preparation facilities and have made major reductions in labor costs. The financially weaker elements of the industry have turned to either opportunists' methods of mining, or have attempted to operate non-union, or else have closed.

With production off 70 million tons since 1951 and prospects for further decline in tonnage for 1953, together with the coal industry's profits approaching or below the zero point, a revolution of coal mining must, of necessity, be in the making. Obviously, in a situation where the cost of production cannot be realized, due to the low prices being paid at the mines, there is little incentive to try to improve the quality or even maintain present standards. There is a growing tendency on the part of many buyers to arbitrarily set the cost per million Btu and to hold all suppliers to this price. Apparently a fetish is being made of trying to reduce prices without full consideration of all the factors involved.

Effect on Air Pollution

If buyers continue the trend towards buying the lowest cost coal possible, without regard for anything except the lowest cost per million Btu delivered, the effect on air pollution cannot help but be greatly increased. If the ash content of the coal used in a plant is increased from 7% to 14%, it cannot help but more than double the atmospheric pollution from the plant. The same is also true of increases in sulfur content. It has been the practice of the utilities and many large industrial plants to include anti-air-pollution equipment in the design of the plant, although it may be miles from even a small village. This anti-air-pollution equipment may cost one or more million dollars.

The effect of air pollution is not as serious from a utility or large manufacturing plant in a remote location, as it is from the plants in or on the fringes of a city. The utility or other plants which, due to the geographic, transmission, transportation, or other problems, cannot be located at a "safe" distance from the thickly populated areas, are in a different position. The only site with adequate cooling water may be in an already crowded industrial and residential area on the banks of a large river, on a lake front, or on a bay. In this case, particularly in a river valley, disposal of waste products is becoming a difficult problem. Sulfur and other fumes are particularly hard to handle. The nylon consuming fumes from an oil-fired plant or plants in Jacksonville is one example of a freak but interesting case. The most serious problem is created by the industrial plant without adequate anti-air-pollution safeguards which is using a low-grade coal.

One obvious method of holding both sulfur and fly ash to a minimum is to use the best coals obtainable. As an example, take a 10 square mile area using 4,000,000 tons of coal per year. Assume that fly-ash collecting equipment will hold the stack discharge to 15% of the ash in the coal, and that only half of the sulfur will leave the stack as SO_2. Two of the available coals are: One with 13,800 Btu per pound, 4.8% ash, and 1% sulfur; the other with 10,300 Btu per pound, 19.2% ash and 5% sulfur.

Coal No. 1

Annual tonnage @ 13,800 Btu/Lb.: 4,000,000 tons
Total ash @ 4.8% = 192,000 tons
Total sulfur @ 1% = 40,000 tons
Fly-ash emission 15% of ash = 28,800 tons
Sulfur in flue gas 50% of total sulfur = 20,000 tons
SO_2 from 50% of total sulfur = 40,000 tons
Fly-ash emitted per square mile per month = 240 tons

Coal No. 2

Annual tonnage: 11,300 Btu/Lb.: 5,359,400 tons
@ 19.2% = 1,029,000 tons
@ 5% = 267,970 tons
@ 15% = 154,350 tons
@ 50% = 133,985 tons
@ 50% = 267,970 tons
1,286 tons

Although this example shows the extremes in coals available to this district, it serves to illustrate the pollution problem and how it may be helped.

Advantages of Good Coal to the Consumer

The cost per ton at the plant or the cost per million Btu delivered is often used as the only yardstick to measure the value of the coals offered to a given plant. Oftentimes the purchase of a coal hinges on a difference of only a few tenths of a cent per million Btu delivered. The effect of other factors than straight Btu cost has been noted by a number of authors. F. M. Reiter (4), B. E. Tate (5), C. H. Frick (6), and Pease and Brandon (7) variously estimate the effect of some of these other factors at 39c to 69c per ton.

A recent study of a moderately sized plant, which could maintain steam pressure of either of two coals is shown in Table 3. The costs given in this table are based on actual experience. There would be some variation of costs in other installations, due to different types of equipment and other conditions. This table serves to illustrate that careful consideration of all the engineering factors, including the cost of using the coal, is necessary for the consumer to accurately measure the cost of coal in his plant. Even where the better, low-ash, and low-sulfur coals do cost slightly more, after all the factors have been taken into consideration there is still a point of the esthetic or human relations value.

The factory and utility plants being built today are usually well designed architecturally, are landscaped, and are built to improve the looks of the site. Formerly, a factory was designed and built for maximum production at the lowest cost, and if it happened to be an eyesore, as many of them were, that was considered one of the prices which had to be paid for the benefits of industrial activity. Every effort is now made to make the factory or power plant a safe and pleasant place in which to work. Additional investment to achieve these ends and even higher operating costs are today considered well worthwhile by plant management. Additional effort and carefulness in coal selection to give the minimum of air pollution, is merely another step in this same human or public relations program which is oftentimes overlooked, or perhaps not even realized by this same management.

Coal is by far the most economical fuel in the eastern part of the United States. Every coal-producing field has good coal available and, if it is properly evaluated, it can usually be shown to be the most economical fuel a plant can use. From the standpoint of human relations, in line with the trend toward good neighborliness, plant management should show greater consideration to the air-pollution problem in addition to the dollars and cents cost of the fuel. To continue the policy of buying only the lowest cost fuel, either on a mine price or on a price f.o.b. the plant, is to jeopardize the quality of the coal being produced in this country at an enormous expense to both the established and responsible coal producers, the consumer of coal, and the general public.

References

(1) Paper entitled "Mechanized Coal Mining and Cleaning and Their Effect on Reduction of Air Pollution," presented at 46th Annual Convention of Air Pollution Control Association, Lord Baltimore Hotel, Baltimore, Maryland (May 25, 26, 27, 28, 1953) on Wednesday, May 27, 1953.

(2) Editorial in *Coal Age,* May 1953, by Ivan Given, Editor.

(3) "Bituminous Coal," by Dr. C. J. Potter, *Mining Congress Journal,* February 1953, pages 58-60.

(4) "Techniques in Coal Procurement," by F. M. Reiter, to be published by *Power Engineering.*

(5) "Which Coal is Best," by B. E. Tate, *Utilization,* January 1953, pages 30-31.

(6) "Selection of Coal for Power," by C. H. Frick, *Coal Age,* November 1952, pages 57:70-5.

(7) "A Pattern for Sound Fuel Procurement," by Marshall Pease, Jr., and Raymond J. Brandon, *Mining Engineering,* pages 177-182.

(Tables on following page.)

TABLE 1

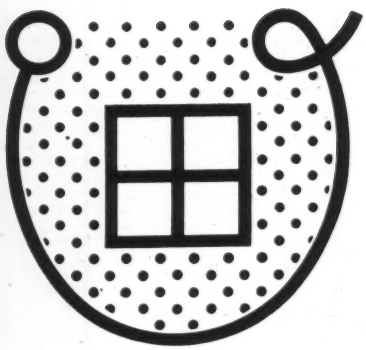
COST AND HEATING VALUE OF COAL USED BY A LARGE MIDWESTERN PLANT

(1937-1952 Inclusive)

Year	Avg. Btu Per Lb. A	Avg. Mine Price—$ B	Avg.* Freight $ C	Avg. Del. Cost Per Ton—$ D	Avg. Cost Per MM Btu—c E
1937	13575	1.69	2.04	3.73	13.75
1938	13790	1.64	2.14	3.78	13.70
1939	13650	1.59	2.14	3.73	13.65
1940	13750	1.61	2.14	3.85	14.00
1941	13635	2.17	2.14	4.31	15.75
1942	13615	2.34	2.23	4.57	16.80
1943	13470	2.70	2.23	4.93	18.30
1944	13275	3.01	2.23	5.24	19.75
1945	13225	3.04	2.23	5.29	20.00
1946	13185	3.30	2.37	5.67	21.50
1947	12985	4.19	2.58	6.82	26.25
1948	12915	5.23	2.91	8.14	31.50
1949	12865	5.08	3.22	8.30	32.25
1950	13200	4.56	3.27	7.83	29.65
1951	13165	4.56	3.36	7.92	30.08
1952	13175	4.23	3.59*	7.82	29.89

the costs averaged for the year. The 4c transporation tax is included.
*All increases in freight rates were applied as they became effective and

TABLE 2

COMPARATIVE ANNUAL FUEL COSTS IN A PLANT REQUIRING 695.5 BILLION BTU

Coal Analysis, As-Received	COAL A 1¼" x 0		COAL B 1¼" x 0
1. Moisture—%	3.95		6.18
2. Ash—%	3.97		9.55
3. Sulfur—%	0.70		4.49
4. Ash Softening Temp. °F	27.80		2070
5. Btu per lb.	13910		11740
Operating Costs			
6. Tons of coal required	25,000		29,620
7. Mine price of coal—$	4.70		2.90
8. Freight rate—$	4.70		4.70
9. Del. cost per ton—$	9.40		7.60
10. Del. cost per million Btu—$	.33.79		.32.37
11. Total del. fuel cost—$	235,000.00		225,112.00
12. Storage loss, weathering, fires, etc (3 M tons stg.) 5%—$	141.00	15c/ton	3,420.00
13. Unloading and handling labor, 30c/ton—$	7,500.00	30c/ton	8,886.00
14. Coal handling equip. maintenance 5c/ton—$	1,250.00	15c/ton	4,443.00
15. Soot blowing and slag removal 1c/ton—$	250.00	5c/ton	1,481.00
16. Pressure parts and fly-ash collection erosion—2c/ton—$	500.00	8c/ton	2,369.60
17. Corrosion of fly-ash collector, fans and stack—$		Per Year	2,000.00
18. Ash-handling equip. operation and maintenance—1c/ton—$	250.00	5c/ton	1,481.00
19. Fly-ash return system maintenance 1c/ton—$	250.00	6c/ton	1,777.20
20. Grate and feeder maintenance 3c/ton—$	750.00	14c/ton	4,146.80
21. Total operating cost—$	10,891.00		30,004.60
22. Total fuel and operating cost—$	245,891.00		255,116.60
23. Utilization cost per ton—$	9.84		8.61
24. Utilization cost per million Btu—c	.35.37		.36.70
25. ANNUAL SAVINGS BY USING COAL A—$	9,225.60